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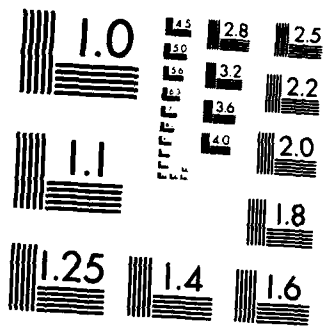

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FOREIGN TECHNOLOGY DIVISION

FORGING AND STAMPING NONFERROUS METALS. HANDBOOK

by

N. I. Korneyev, V. M. Arzhakov, et al

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By: N. I. Korneyev, V. M. Arzhakov, et al

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

FORGING AND STAMPING NONFERROUS METALS. Handbook.

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V.Ya. Kleymenov, G.A. Nekrasova, L.A. Nikol'skiy, S.B. Pevzker,
T.N. Sazonova, I.G. Skugarev, Ye.N. Timokhina, Ye.M. Eyfir, K.P. Yatsenko

Page. 2.

The information about the chemical composition, the physical and mechanical properties, the thermomechanical parameters, the technological processes of forging and stamping of nonferrous metals and alloys on their basis is given in the handbook.

Handbook is intended for the production engineers and the designers. It can be useful to students and instructors of VTUZ [higher technical educational institution].

Page 3.

Chapter 1.

METALS AND ALLOYS.

Forms of alloys, their characteristic and use/application.

Aluminum alloys.

Classification, chemical composition, physical and mechanical properties and technological characteristics are given in table 1-5

and Fig. 1-26.

During the construction of forgings in stampings together with the strength one must take into account the specific weight/gravity, which determines density of metal. Should be considered also the thermal coefficient of linear expansion and the possibility of a decrease in corrosion resistance of pairs (parts from aluminum and alloys on its basis, which contact with the parts and the assemblies from other metals).

The values of the coefficient of thermal conductivity and specific heat can be used during calculations of the time of heating and cooling of forgings and stampings.

Magnesium alloys.

Classification and designation/purpose, chemical composition and mechanical properties are given in Table 6-14 and Fig. 27-56. Magnesium alloys have low density, high ability to absorb energy of impact/shock and vibrations.

Their high specific heat is also the positive property of magnesium alloys. The temperature of the surface of parts of these alloys with an identical quantity of exchanged heat is 2 times lower

in comparison with the temperature of the surface of parts of low-carbon steel and to 15-20% lower than in parts from the aluminum alloys.

1. Classification on the strength of aluminum and alloys on its basis.

(1) Группа	(2) Прочность и пластичность	(3) Сплав	(4) Механические свойства	
			$\sigma_в$ в кГ/мм² (5)	δ в % (6)
I	(7) Мягкие, пластичные	АД, АВ; АМц; АМг1; АМг2; АД31; АД33	(8) Менее 30	(9) 5—22 (в зависимости от степени нагартовки)
II	(10) Средней прочности и пластичности	Д1, АК2; АК4; АК4-1; АК6; АК6-1; ВД17; АМг6	30—45	10—15
III	(11) Высокой прочности с пониженными технологическими свойствами	АК8; В93; В95; В96; ВАД23	(12) Более 45 (до 60 и выше)	5

Key: (1). Group. (2). Strength and plasticity. (3). Alloy. (4). Mechanical properties. (5). in kg/mm². (6). δ in %. (7). soft, plastic. (8). It is less. (9). depending on degree of work hardening. (10). Average/mean strength and plasticity. (11). High strength with lowered/reduced technological properties. (12). More than 45 (to 60 and above).

Pages 4+5.

2. Chemical composition of aluminum and alloys on its basis.

(3) Сплав	(1) Легирующие элементы в %					(2) Вредные примеси в % (не более)									
	Cu	Mg	Mn	Si	(4) Другие	Si	Fe	Cu	Mn	Ni	Zn	Mg	(5) Прочие	(6) Сумма Fe + Si или Fe + Ni	(7) Сумма всех примесей
Алюминий (8)															
АД1	—	—	—	—	—	0.35	0.3	0.05	—	—	—	—	0,1	0.6Fe + Si	0.7
АД						0.55	0.5	0.1	0,1		0,1	0,1		1,0Fe + Si	1.2
Алюминиево-марганцевые сплавы (9)															
АМц	—	—	1.0—0,6	—	—	0.6	0.7	0.2	—	—	0.1	0,05	0.1	—	1.75
АМц2		0.8–1.3	0.9—1.4			0.7		0.1			—	—			1.6
Магналии (10)															
АМг1		0.5—1.8	—			0.05	0.05	0.01			—		0.07	—	0.18
АМг2		1.8—2.8	0.2—0,6		—	0.4	0.4	0.1						0.6Fe + Si	
АМг3		3.2—3.8	0.3—0,6			—	0.5								
АМг4	—	3.8—4.8	0.5—0.8	—	0.05—0.25Cr 0.02—0.1Ti; 0.0001—0.005Be			0.05	—	—	0.2	—	0.1	—	—
АМг5П		4.7—5.7	0.2—0.6		—	0.4	0.4	0.2			—	—		0.6Fe + Si	
АМг6		5.8—6.8	0.5—0.8		0.02—0.1Ti; 0.0001—0.005Be			0.1			0.2			—	1.2
Заклепочные сплавы (11)															
Д18П	2.2—3.0	0.2—0.5	—	—	—	0.5	0.5	—	0.2	01, Ti	0.1	—	0.1	—	1.4
В65	3.9—4.5	0.15—0.3	0.3—0.5			0.25	0.2	0.1Ti	—	—				0.45Fe + Si	0.65
Дуралюмины (12)															
Д1	3.8—4.8	0.4—0.8	0.1—0.8	—	—	0.7	0.7	—	—	0.1	0.3	—	0.1	—	1.2
ВД17	2.6—3.2	2.0—2.4	0.45—0.7			0.3	0.3			—	0.1	—		0.6Fe + Si	0.[illegible]

								Жаропрочные сплавы (13)								
Д20	6—7	—	0.4—0.8	—	0.1—0.2Ti	0.3	0.3		—	0.2	0.1	0.05				1.05
АК2	3.5—4.5	0.4—0.8		0.5—1.0	1.8—2.3Ni											0.6
АК4			—	0.5—1.2	0.1	—	—		0.2	—	0.3	—	0.1	—		0.95
АК4-1	1.9—2.5	1.4—1.8			1.0—1.5Ni	0.35										0.6
ВАД23	4.9—5.8	—	0.4—0.8	—	0.1—0.25Cd 0.1—1.4Li	0.3	0.3	—		0.15	0.1	0.1				
САП-1 САП-2 САС-1	—	6—9 9—13 —	} Al_2O_3 —	 25—30	— 5—7Ni	—	0.2 —		—	—	—	—	0.25 жир—0.1H_2O (14)			—
								Ковочные сплавы (15)								
АК6					—											
АК6-1	1.8—2.6	0.4—0.8	0.4—0.8	0.7—1.2	0.01—0.2Cr; 0.02—0.1Ti	—	0.2	—	—	0.1	0.3	—	0.1	0.7P	[illegible]	1.1
АК8	3.9—4.8	0.4—1.0	0.4—1.0	0.6—1.2	—											1.2
								Высокопрочные сплавы (16)								
B93	0.8—1.2	1.6—2.2	—		6.6—7.5Zn 0.15—0.4Fe	0.2	—		0.1	0.1Ti					—	0.5
B95	1.4—2.0	1.8—2.8	0.2—0.6	—	5.0—7.0Zn 0.1—0.25Cr	0.5	0.5	—	—	—	—	—	0.1		1.0Fe+Si	1.1
B96	2.2—2.8	2.5—3.2	0.2—0.5		7.6—8.6Zn 0.1—0.25Cr	0.3									—	0.9
								Коррозионностойкие сплавы (17)								
АВ	0.2—0.6	0.45—0.9	0.15—0.35	0.5—1.2	—		0.5	—	—	—	0.2		0.1			0.8
АД31	—	0.4—0.9		0.3—0.7				0.1	0.1							1.15
АД33	0.15—0.4	0.8—1.2	—	0.4—0.8	0.15—0.35Cr	—	[illegible]	—	0.15	0.15Ti	0.25	—	0.15		—	1.4
АД35	—	0.8—1.4	0.5—0.9	0.06—1.2	—		0.5	0.1	—		0.2		0.1			—

Key: (1). Alloying elements in %. (2). Harmful impurities in % (not more). (3). Alloy. (4). Others. (5). Other. (6). Sum Fe+Si or Fe+Ni. (7). Sum of all admixtures/impurities. (8). Aluminum. (9). Aluminum-manganese alloys. (10). Magnalium. (11). Riveting alloys. (12). Duralumin. (13). High-temperature (strength) alloys. (14). grease. (15). Forging alloys. (16). High-strength alloys. (17). Corrosion-resisting alloys.

Pages 6+7.

3. Physical properties of aluminum and alloys on its basis.

3. Физические свойства алюминия и сплавов на его основе

(1) Сплав	(2) Плотность в Г/см³	(3) Удельное электросопротивление в ом·мм²/м	(4) Коэффициент теплопроводности в кал/см·сек·°С	(5) Коэффициент линейного расширения α·10⁻⁶ в 1/°С	(6) Удельная теплоемкость в кал/г·°С
АД1	2,71	59% (АМ); 57%* (АН)	0.52 (20) АН	22 (от −50 до +20)	
АД		(удельная электропроводность в % от электропроводности)	0.54 (20) АМ	25.6 (20—300)	
АМц	2.73	40% (АМцН); 50% (АМцМ)	0.43 (25); 0.45 (400) АМцМ	21,6 (от −50 до +20) 25,0 (20—300)	0.26 (100) 0.31 (400)
АМг2	2.68	0.0476	0.37 (25); 0.36 (100)	22.2 (от −5 до +20) 24.3 (20—200)	0.23 (100), 0.26 (400) 0.22 (100)
АМг1	2,7	0.0341	0.44 (25); 0.45 (400)	26,2 (20—400)	0.26 (400)
АМг2	2.68	0.0476	0.37 (25); 0.40 (400)	22,2 (от −50 до +20) 25,8 (20—300)	0.23 (100) 0.26 (400)
АМг3	2.67	0.0496	0.35 (25), 0.36 (400)	23.5 (20—100) 26,1 (20—400)	0.23 (100) 0.255 (400)
АМг4		0.0609	0.32 (25); 0.33 (100)	24,3 (20—100)	0.22 (100)
АМг5В	2.65	0.0640	0.29 (25); 0.35 (400)	—	0.26 (400)
АМг6	2.64	0.0710	0.25 (25); 0.33 (400)	24.7 (20—200) 26.5 (20—400)	0.22 (100) 0.26 (400)
Д18П	2.76	0.039	0.39 (25); 0.46 (400)	23.4 (20—100) 25.2 (20—300)	0.22 (100) 0.26 (400)
В65	2,8	0.0504	0.36 (25); 0.44 (400)	—	0.23 (100)
Д1		0,054 (Д1Т)	0.26 (25); 0.42 (400)	21,8 (от −50 до +20) 25,0 (20—300) 23,6 (20—100)	0.26 (400) 0.19 (100); 0.23 (300) 0.20 (100)
ВД17	2,75	0.055	0.32 (25); 0.41 (400)	26.9 (300—400)	0.23 (400)
М40		0,0613 (М40Т)	0.29 (25); 0.34 (300)	24,2 (20—100)	—

Д20	—	0.0610	0.33 (25); 0.35 (300); 0.36 (400)	22.6 (20—100); 30.2 (300—400)	—
АК2	2.8	0.047	0.37 (25); 0.43 (400)	22.3 (20—100) 24.2 (20—300)	0.18 (100) 0.24 (400)
АК4	2.77	0.05	0.35 (25); 0.41 (400)	21.8 (20—100) 24.9 (20—300)	0.20 (100); 0.25 (400)
АК4-1	2.8	0.055	0.34 (25); 0.38 (400)	19.6 (20—100) 24.7 (300—400)	0.19 (100); 0.22 (350)
ВАД23	—	0.0912	0.23 (100); 0.25 (400)	24 (20—100); 29.9 (300—400)	0.23 (100) 0.31 (400)
САП-1	2.7	0.39	0.42 (20); 0.46 (400)	21.2 (20—100)	0.21 (100); 0.27 (200)
САП-2		0.04		22.9 (100—200)	—
САС-1	2.75	0.105	0.21 (25)	14.5—15.5 (20—100)	0.1 (100); 0.19 (300)
АК6	2.76	0.041	0.42 (25); 0.45 (400)	21.4 (20—100)	0.19 (50)
АК6-1				35.6 (400—500)	0.24 (400)
АК8	2.8	0.043	0.35 (25); 0.42 (400)	25.5 (20—100) 24.5 (20—300)	0.20 (100); 0.26 (400)
В93	2.84	0.0406	0.39 (25); 0.35 (400)	24.1 (20—100) 40.7 (300—400)	0.19 (20); 0.27 (400)
В95	2.85	0.042 (В95Т)	0.37 (25); 0.38 (400)	22 (от −50 до +20) 26.2 (20—300)	—
В96	2.89	0.0579 (В96Т)	0.27 (25); 0.35 (300)	22.84 (20—100) 24.66 (100—200)	0.19 (100)
АВ	2.7	(10) 0.055 (АВТ и АВТ1)	0.37 (25)	21.8 (от −50 до +20)	0.23 (300)
АД31	2.71	0.0344	0.45 (25); 0.52 (400)	24.3 (20—200) 26.7 (20—400)	0.22 (100) 0.25 (400)
АД33		0.0438	0.36 (25); 0.41 (300)	24.1 (20—200) 25.0 (20—300)	0.225 (100) 0.25 (300)
АД35	2.89	0.038	0.44 (25)	24 (20—200)	0.21 (100)

[1] В скобках указана температура в °С.

Key: (1). Alloy. (2). Density in g/cm^3. (3). Specific resistance in $\Omega \cdot mm^2/m$. (4). Coefficient of thermal conductivity[1] in cal/cm·s °C.

FOOTNOTE [1]. The temperature in °C is indicated in brackets. ENDFOOTNOTE.

(5). Coefficient of linear expansion [1] $\alpha \cdot 10^{-6}$ in 1/°C. (6). Specific heat [1] in cal/g·°C. (7). to. (8). (specific conductivity in % of conductivity). (9). from. (10). and.

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4. Mechanical properties of semi-finished products from aluminum and alloys on its basis.

(1) Сплав	(2) Полуфабрикат	(3) Состояние поставки	(4) $\sigma_в$ в кГ/мм²		(4) $\sigma_{0,2}$ в кГ/мм²		δ_{10} в %	
			(6) Направление вырезки образца					
			(7) вдоль	(8) поперек	(7) вдоль	(8) поперек	(7) вдоль	(8) поперек
АД1 и АД (9)	(10) Прутки всех размеров	(11) Нагартованный Отожженный	15 8—11		10 3		6 25—35 $l = 5d$	
АМц		(12) Отожженный или термически не обработанный	Не более 17 (13)				20 $l = 5d$	
АМг1	(14) Штамповки Поковки	(15) Отожженный	17		—		16 $l = 5d$	
АМг2	(16) Прутки всех размеров		16—23				10 $l = 5d$	—
		(17) Полунагартованный	25		21		6	
АМг3	(14) Штамповки Поковки	(15) Отожженный	19	—	7 17	—	15	
АМг5	(14) Штамповки Поковки		28		15			
АМг6	(14) Штамповки Поковки	(17 a) Отожженный (в зависимости от веса)	29—32		12—16		11—15	
Д18П	(17 b) Прутки и проволока	(18) После закалки и естественного старения Отожженный	30 16		17 6		24	$\tau_{ср}$ 20 —
В65	Проволока (19)	(20) После закалки и естественного старения	40		—		20	$\tau_{ср}$ 25—28
Д1	(14) Штамповки	(21) После закалки и старения	38	36	20	18	12	6
	Поковки		36	34	—	—	10	5
ВД17	Штамповка		40	—	28			—
М40	(14) Поковки			38	30	28	10 $l = 5d$	8
Д20	(14) Штамповки Поковки	(22) После закалки и искусственного старения	38	37	26		10	4
Д21	(14) Штамповки Поковки		40	38	27 26	—	7 6	4 3
АК2	(14) Штамповки Поковки		37 36	—	24 —		5 4	—

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Continuation Table 4.

Сплав	Полу-фабрикат	Состояние поставки	$\sigma_в$ в $кГ/мм^2$ вдоль	$\sigma_в$ в $кГ/мм^2$ поперек	$\sigma_{0,2}$ в $кГ/мм^2$ вдоль	$\sigma_{0,2}$ в $кГ/мм^2$ поперек	δ_{10} в % вдоль	δ_{10} в % поперек
			Направление вырезки образца					
АК4	Штамповки (14)	(22) После закалки и искусственного старения	38	–	28	–	4	–
	Поковки		36		–		3	
АК4-1	Штамповки (14)		40	38	28		5	4
	Поковки		38		–		4	
ВАД-23	Прутки (23)		55—60		50—52			
ОАП-1	(24) Прутки и полосы	(25) Термической обработке не подвергаются	29—31	–	30		7—9 $l = 5d$	–
ОАП-2			32		–		4 $d = 5$	
ОАС-1	(25) Прутки		22—24		21—23		0,5	
В95	Штамповки	(22) После закалки и искусственного старения	52	40	41	–	6	4
	Поковки		50	45	42		5	3
В93	Штамповки		49	49	44	44	6	3,5
	Поковки		48	48		43		
В96	Штамповки		60	54	54		5	3
	Поковки (14)		57	52	50		4	
АВ	Штамповки		30	27	22	–	12	–
	Поковки		28	–	–		10	
АК6	Штамповки		39	37	28	25		7
	Поковки		37	35	–	–	8	6
АК6-1	Штамповки		39	37	28	25	10	7
	Поковки		37	35	–		8	6
АК8	Штамповки		44	40	32		10	
	Поковки		42	36	–		8	4
АД31	(26) Прутки всех размеров	(27) После закалки и естественного старения	14		7		13	
		(22) После закалки и искусственного старения	20		15		8	
АД33	(26) Прутки всех размеров	(27) После закалки и естественного старения	18	–	11	–	15	–
		(22) После закалки и искусственного старения	27		23		10	
АД35	(24) Прутки и полосы	(27) После закалки и естественного старения			20		10—15	
		(22) После закалки и искусственного старения	33		28		8	

Key: (1). Alloy. (2). Semi-finished product. (3). State of delivery.

(4). in kg/mm². (5). in %. (6). Direction of cut of sample/specimen. (7). lengthwise. (8). across. (9). and. (10). Rods of all sizes/dimensions. (11). Cold-worked. Annealed. (12). Annealed or not heat-treated. (13). not more. (14). Stampings. Forgings. (15). Annealed. (16). Rods of all sizes/dimensions. (17). Partly gathered. (17a). Annealed (depending on weight). (17b). Rods and wire. (18). After hardening and natural aging annealed. (19). Wire. (20). After hardening and natural aging. (21). After hardening and aging. (22). After hardening and artificial aging. (23). Rods. (24). Rods and band. (25). they do not undergo heat treatment. (26). Rods of all sizes/dimensions. (27). After hardening and natural aging.

Page 10.

5. Technological characteristics of aluminum alloys.

(1) Сплав	(2) Прочность при 20°	(3) Максимальный диаметр слитка в мм	(4) Степень сложности получаемых штамповок	Температура применения (5) в °С
АК6; АК6-1	Средняя (6)	1100—1200	(9) Наиболее сложные	150—180
АК8	Высокая (7)		(10) Средней сложности	
АК4-1	Средняя (6)		(11) Сложные	(14) До 250
В-93	Высокая (7)	1100	Средней сложности (10)	До 100—120 (14)
А-В	Малая (8)	500—600	Наиболее сложные (9)	
АД31 АД33 АД35	(12) Малая, невысокая, средняя			До 150—180 (14)
АД; АД1 АМг1 АМг2 АМг3 АМг4 АМг5В АМг6		500—1100	(13) Сложные и несложные	
Д1	Средняя (6)	До 800	(10) Средней сложности	(14) До 150
В95; В96	Высокая (7)	300—500		До 100—120
ВАД-23		500—600	(17) Несложные	До 160—180
Д20	Средняя (6)	1100		До 300
САП-1 САП-2	Невысокая и средняя (15)	-	(16) Средней сложности	300—500

Key: (1). Alloy. (2). Strength at 20°. (3). Maximum/overall diameter of ingot in mm. (4). Degree of complexity of obtained stampings. (5). Temperature of use/application in °C. (6). Average/mean. (7). High. (8). Low. (9). Most complicated. (10). Average/mean complexity. (11). Complicated. (12). Low, low, average/mean. (13). Complicated and uncomplicated. (14). To. (15). Low and average/mean. (16). Average/mean complexity. (17). Uncomplicated.

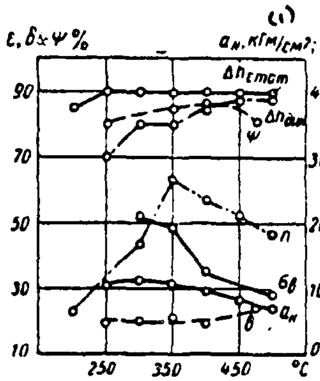

Fig. 1.

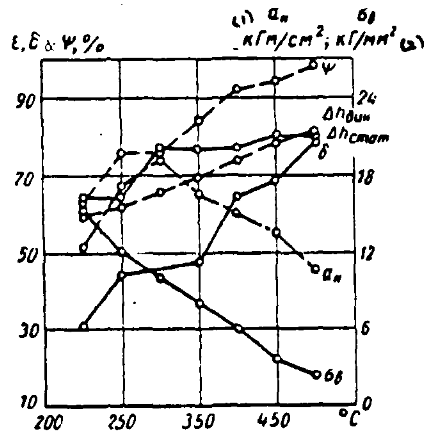

Fig. 2.

Fig. 1. Diagram of plasticity of aluminum alloy AMts (pressed).

Key: (1). kgfm/cm². (2). kg/mm².

Fig. 2. Diagram of plasticity of aluminum alloy AMg (pressed).

Key: (1). kgfm/cm². (2). kg/mm².

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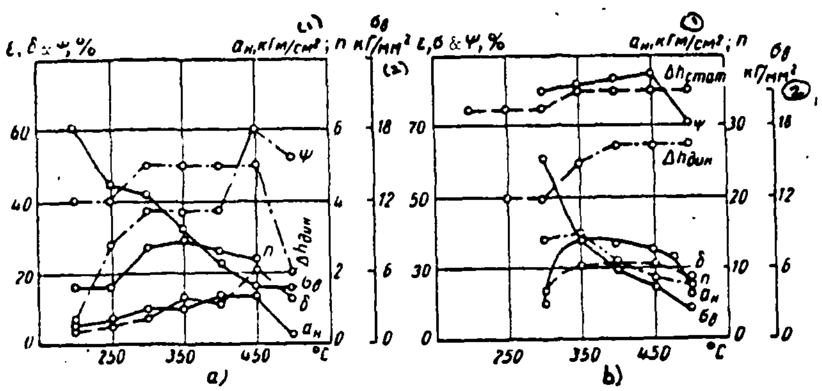

Fig. 3. Diagram of plasticity of aluminum alloy AK6; a) cast; b) deformed.

Рис. 3. Диаграмма пластичности алюминиевого сплава АК6: а)— литой; б)— деформированный

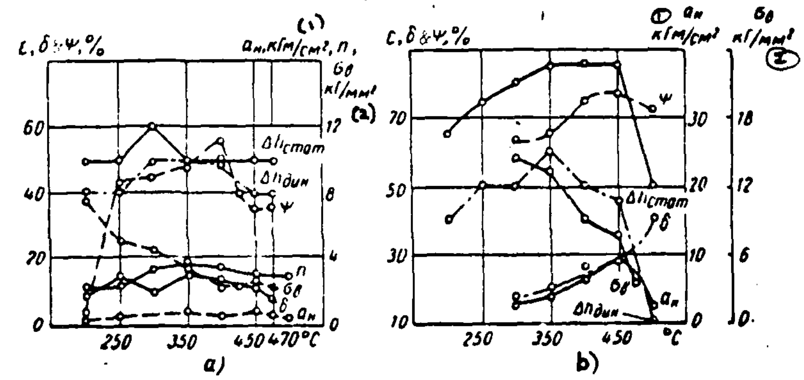

Fig. 4. Diagram of plasticity of aluminum alloy AK8: a) cast; b) deformed.

Key: (1). kgfm/cm². (2). kg/mm².

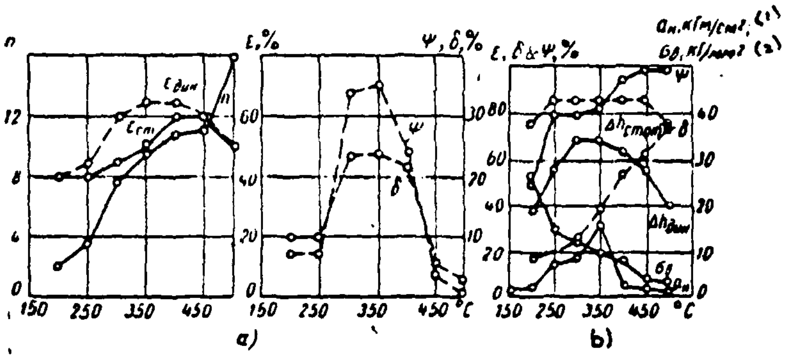

Fig. 5. Diagram of the plasticity of aluminum alloy B93: a) ingot ∅ of 145 mm; b) deformed.

Key: (1). kgfm/cm². (2). kg/mm².

Page 12.

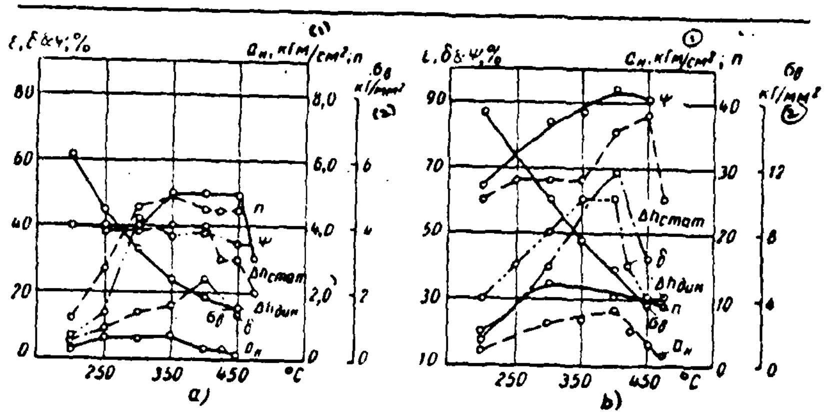

Fig. 6. Diagram of plasticity of aluminum alloy B95: a) cast; b) deformed.

Key: (1). kgfm/cm². (2). kg/mm².

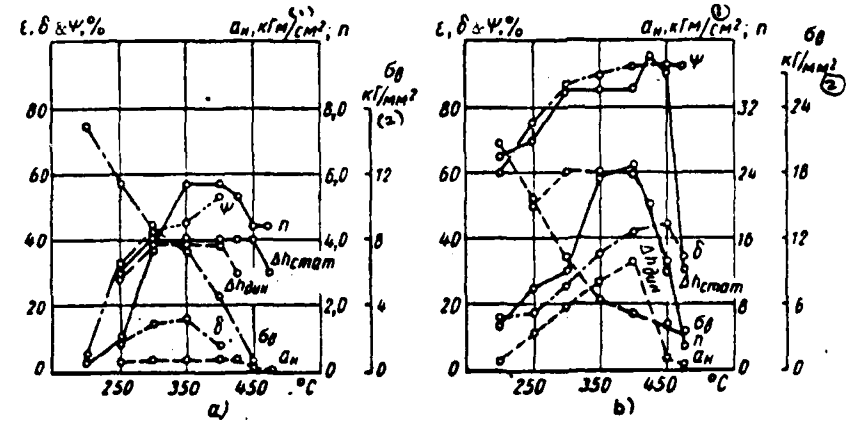

Fig. 7. Diagram of the plasticity of aluminum alloy B96: a) cast; b) deformed.

Key: (1). kgfm/cm². (2). kg/mm².

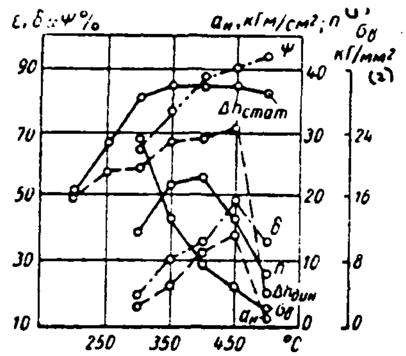

Fig. 8.

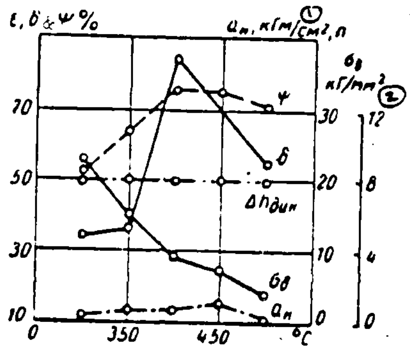

Fig. 9.

Fig. 8. Diagram of plasticity of aluminum alloy ВД17 (pressed).

Key: (1). kgfm/cm². (2). kg/mm².

Fig. 9. Diagram of plasticity of aluminum alloy AK4 (pressed).

Key: (1). kgfm/cm². (2). kg/mm².

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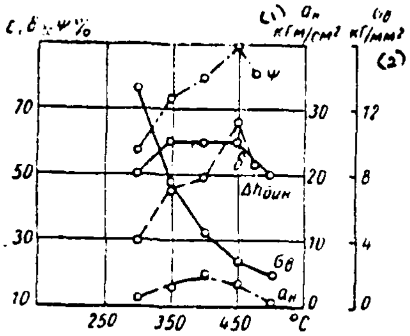


Fig. 10.

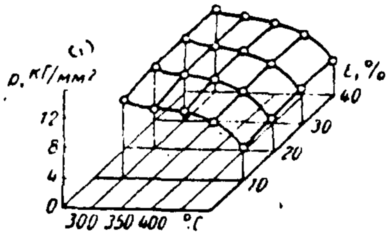


Fig. 11.

Fig. 10. Diagram of plasticity of aluminum alloy AK4-1 (pressed).

Key: (1). kgfm/cm². (2). kg/mm².

Fig. 11. Curves of flow of aluminum alloy AMts (pile driver).

Key: (1). kg/mm².

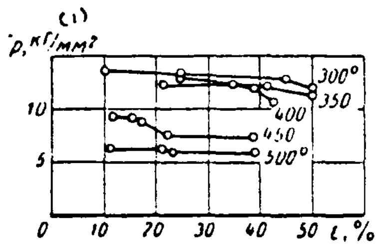


Fig. 12.

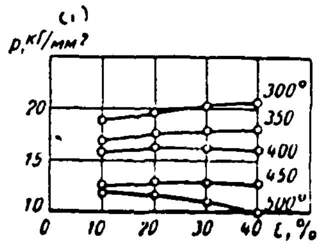


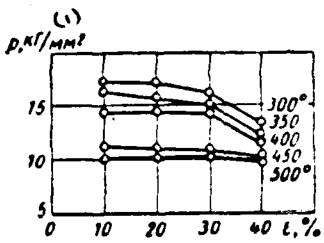
Fig. 13.

Fig. 12. Curves of flow of aluminum alloy AK6 (pile driver).

Key: (1). kg/mm².

Fig. 13. Curves of flow of aluminum alloy B95 (pile driver).

Key: (1). kg/mm².



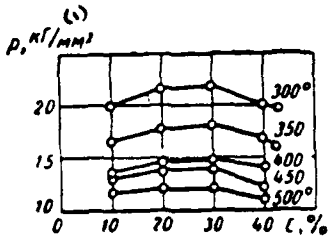


Fig. 14.

Fig. 15.

Fig. 14. Curves of flow of aluminum alloy ВД17 (pile driver).

Key: (1). kg/mm².

Fig. 15. Curves of flow of aluminum alloy AK4 (pile driver).

Key: (1). kg/mm².

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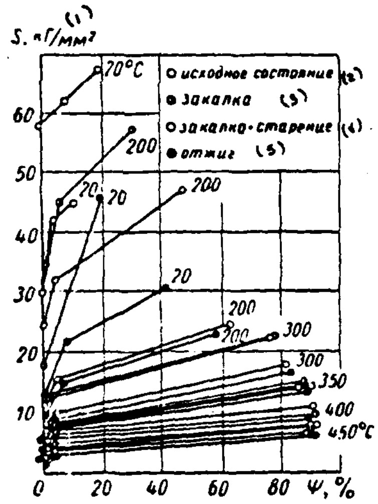

Fig. 16.

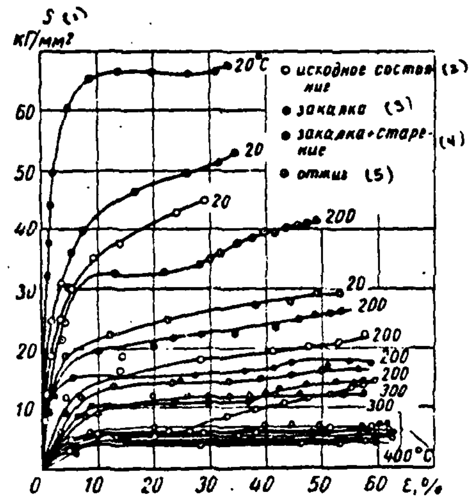

Fig. 17.

Fig. 16. Diagram of actual stresses with elongation of high-alloyed aluminum alloy B95 (N. I. Korneyev, I. G. Skugarev, I. K. Kolpashniko).

Key: (1). kg/mm². (2). initial state. (3). hardening. (4). hardening+aging. (5). annealing.

Fig. 17. Diagram of actual stresses during compression of high-alloyed aluminum alloy B95 (N. I. Korneyev, I. G. Skugarev, I. K. Kolpashniko).

Key: (1). kg/mm². (2). initial state. (3). hardening. (4). hardening—aging. (5). annealing.

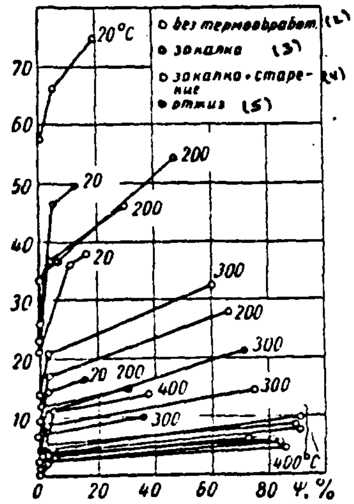

Fig. 18.

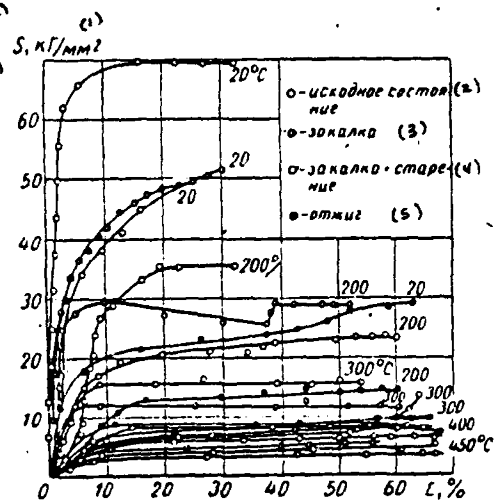

Fig. 19.

Fig. 18. Diagram of actual stresses with elongation of high-alloyed aluminum alloy of type B96 (N. I. Korneyev, I. G. Skugarev, I. K. Kolpashnikova).

Key: (1). kg/mm². (2). without heat treatment. (3). hardening. (4). hardening aging. (5). annealing.

Fig. 19. Diagram of actual stresses during compression of high-alloyed aluminum alloy of type B96 (N. I. Korneyev, I. G. Skugarev, I. K. Kolpashnikova).

Key: (1). kg/mm². (2). initial state. (3). hardening. (4). hardening aging. (5). annealing.

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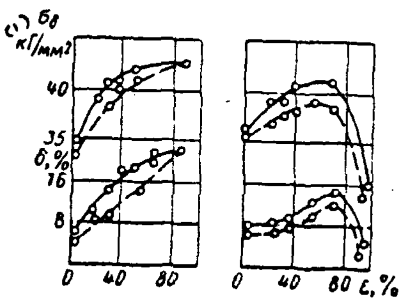

Fig. 20.

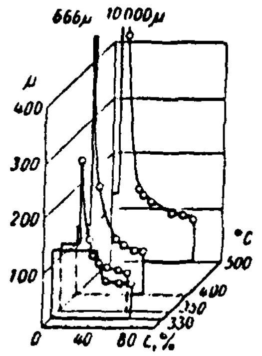

Fig. 21.

Fig. 20. Effect of general/common/total strain on mechanical properties of aluminum alloy Д1 (V. A. Livanov): - center; - - - periphery.

Key: (1). kg/mm².

Fig. 21. Diagram of recrystallization of working aluminum (Si=0.13%; Fe=0.2%). Rounds, are hotter settling, annealing at a temperature of settling and flow 20 min in salt bath.

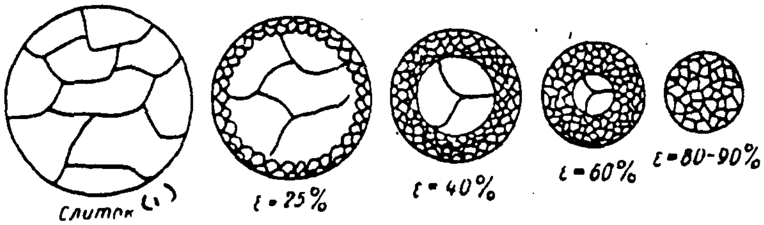

Fig. 22. Change in macrostructure of pressed rod from aluminum alloy in dependence on general/common/total strain (diagram).

Key: (1). ingot.

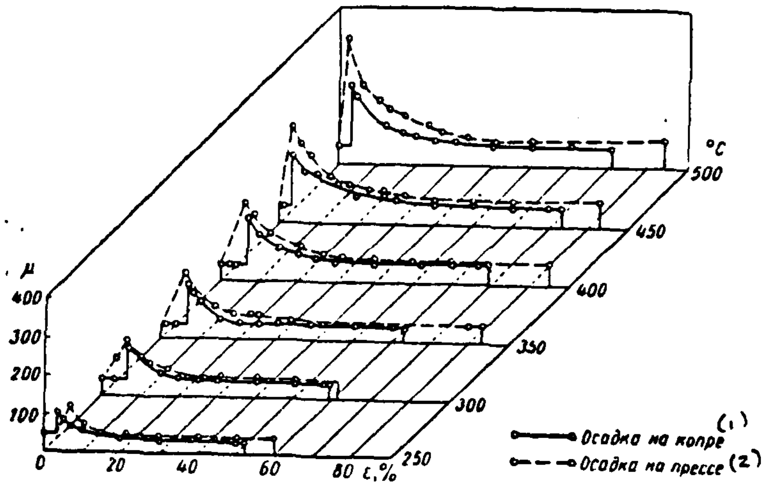

Fig. 23. Diagram of the recrystallization of Duralumin Д1 annealing with 500°C for 3 h.

Key: (1). upsetting on the pile driver. (2). upsetting on press.

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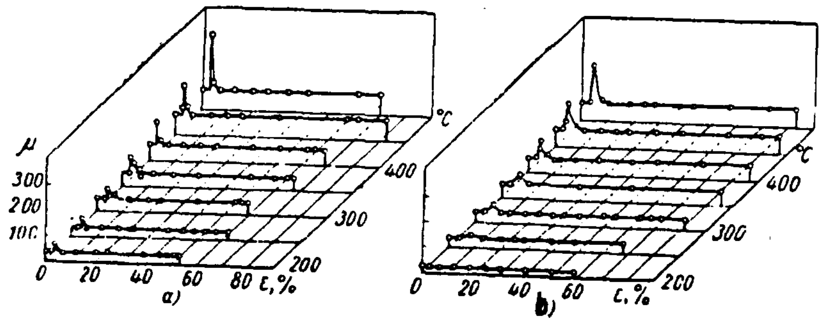

Fig. 24. Diagram of recrystallization of aluminum alloy ВД17: a) upsetting on press; b) upsetting on pile driver.

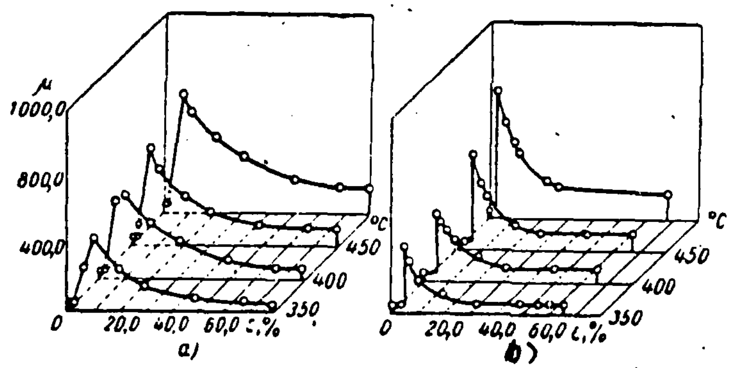

Fig. 25. Diagram of recrystallization of aluminum alloy AK6; a) upsetting on press; b) upsetting on pile driver.

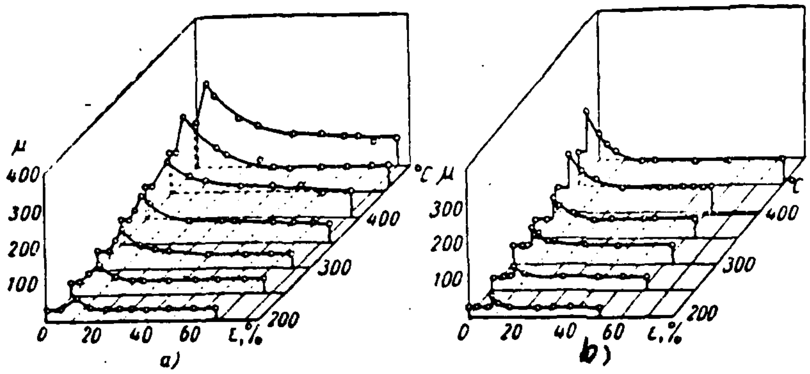

Fig. 26. Diagram of the recrystallization of aluminum alloy AK8; a) upsetting on the press; b) upsetting on the pile driver.

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6. Classification and designation/purpose of magnesium alloys.

(1) Группа	(2) Прочность $\sigma_в$ в кГ/мм²	(3) Сплав	(4) Система сплава	Пластичность в интервале температур горячей деформации (5)	(6) Рабочая температура деталей в °C (не более): при длительной работе (7)	при кратковременной работе (8)	(9) Назначение
I	(10) Невысокой прочности 17—23	МА1	Mg — Mn	(11) Высокая	До 150 (16)	До 200 (16)	(12) Штамповки несложной конфигурации, не несущие больших перегрузок
II	(14) Средней прочности 23—28	МА8	Mg — Mn — 0,2% Ce	(15) Хорошая	До 200 (16)	До 250 (16)	(13) Все виды деформируемых полуфабрикатов и штамповки для деталей средней прочности и сложные по форме
		МА9	Mg—Mn—0,5Al—0,2Ca				(17) Прессованные полуфабрикаты для деталей средней прочности
		МА2	Mg — Al — Zn — Mn		До 150	До 200	(18) Кованые и штампованные детали сложной формы для работы в условиях средних нагрузок
III	(22) Высокой прочности 26—34	МА2-1	Mg — Al — Zn — Mn	(20) Удовлетворительная			(19) Все виды деформированных полуфабрикатов для деталей сложной формы. Применение свободной ковки ограничено
		МА3[1]	Mg — Al — Zn — Mn				(21) Штамповки заготовок для нагруженных деталей по форме средней сложности. Свободная ковка — не рекомендуется
		МА5[1]	Mg — Al — Zn — Mn	Пониженная (23)			(24) Штамповки нагруженных деталей по форме средней сложности. Свободной ковкой не обрабатывается
		ВМ65-1	Mg — Zn — Zr	(15) Хорошая	125—150	До 200	(25) Имеет наиболее широкое применение в промышленности для изготовления крупногабаритных нагруженных деталей сложной формы. Допускаются простые операции свободной ковкой
IV	(26) Жаропрочные	ВМ17[1]	Mg — Ce — Mn	Удовлетворительная (20)	До 200	До 250	(27) Детали для работы в условиях повышенной температуры. Медленно разупрочняющиеся детали при температурах > 200° C
		МА11[1]	Mg — Nd — Mn — Ni		250	300—350	
		МА13[1]	Mg — Th — Mn	Хорошая (15)	350	400	
		ВМД1	Mg — Th — Mn	Удовлетворительная (20)			

Notes: 1. Alloys MA1, MA3 and MA5 are applied limitedly. 2. Alloys MA9, MA11, MA13, BM1 and BM17 are applied for manufacturing parts, which work under overheat conditions. 3. alloys MA13 and BMД1 contain radioactive thorium in their composition; therefore all forms of processing must be accomplished in accordance with special rules.

Key: (1). Group. (2). Strength in kg/mm². (3). Alloy. (4). System of alloy. (5). Plasticity in range of temperatures of hot

deformation. (6). Operating temperature of parts in °C (not more). (7). with continuous operation. (8). with momentary duty. (9). Designation/purpose. (10). Low strength. (11). High. (12). Stampings of uncomplicated configuration, which do not carry heavy overloads. (13). All forms of semi-finished products being deformed and stamping for parts of average/mean strength and complicated on form. (14). Average/mean strength. (15). Good. (16). To. (17). Pressed semi-finished products for parts of average/mean strength. (18). Forged and stampings of intricate shape for work under conditions of medium loads. (19). All forms of deformed semi-finished products for parts of intricate shape. The use/application of smith forging is limited. (20). Satisfactory. (21). Stampings of blanks for loaded parts on form of average/mean complexity. Smith forging - is not recommended. (22). High strength. (23). Lowered/reduced. (24). Stampings of loaded parts on form of average complexity. It is not worked by free ductile. (25). Has widest application in industry for manufacturing large-size loaded parts of intricate shape. The simple operations of free ductile are allowed/assumed. (26). High-temperature (strength). (27). Parts for work at elevated temperatures. Slowly weakening parts at temperatures of >200°C.

FOOTNOTE [1]. They have the lowered/reduced plasticity, especially in the cast state. ENDFOOTNOTE.

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7. Chemical composition of magnesium alloys.

(1) Сплав	(2) Легирующие элементы в %			(3) Примеси в % (не более)							
	Al, Cd, Nd, Th	Mn, Zr	Zn, Ca, Ni, Ag	Al	Cu	Be	Ni	Zn	Si	Fe	(4) Прочие
МА1	0,3Al	—	—	—		0,2		0,3			0,2
МА8	—	1,5—2,5Mn	0,15—0,35Ce	0,3			0,01				0,3
МА9	0,4—0,8Al	1,0—1,8Mn	0,06—0,3Ca	—		—		0,1	0,15		
МА2	3,0—4,0Al	0,15—0,5Mn	0,2—0,8Zn		0,05					0,05	0,03
МА2-1	3,8—5,0Al	0,4—0,8Mn	0,8—1,5Zn	0,1Ca		0,02	0,005	—			0,3
МА3	5,5—7,0Al	0,15—0,5Mn	0,5—1,5Zn	—							
ВМ17	2,5—3,5Cr	1,4—2,2Mn	—	0,2		0,01	0,01	0,2	0,2		—
МА5	7,8—9,2Al	0,15—0,5Mn	0,2—0,8Zn	—				—	0,15		
ВМД3	1,2—2,0Cd	0,45—0,9Zr	2,5—3,5Zn		0,03					0,03	
ВМ65-1	—	0,3—0,9Zr	5,0—6,0Zn	0,05	0,05				0,05	0,05	
МА11	2,5—3,5Nd	1,5—2,5Mn	0,13—0,25Ni		0,03	0,02	0,005	0,2		0,03	0,3
МА13	1,7—2,0Th	0,4—0,8Mn	—	0,2	0,05				0,15		
ВМД1	2,5—3,5Th	1,2—2,0Mn								0,05	
МА10	7,8—8,6Al 7,0—8,0Cd	0,2—0,6Mn	2,0—2,4Ag	—	0,03			0,3			

Key: (1). Alloy. (2). Alloying elements in %. (3). Admixtures/impurities in % (not more). (4). Other.

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8. Physical properties of magnesium.

(1) Наименование показателей	(2) Показатели
Плотность в г/см³ при температуре в ° С: (3)	
20	1,74
650 (твердый) (4)	1,64
650 (жидкий) (5)	1,57
700	1,54
Точка плавления в ° С (6)	650
Точка кипения в ° С (7)	1120
Теплота плавления в кал/г (8)	88,8
Теплота испарения в кал/г (9)	1300
Теплота сгорания в кал/моль (10)	145 000
Удельная теплоемкость при 25° С в кал/г · ° С (11)	0,25
Коэффициент теплопроводности в кал/см · сек · ° С (12)	0,376
Коэффициент линейного расширения α · 10⁻⁶ в 1/° С при температуре в ° С: (13)	
20–100	25,8
20–300	27,0
20–500	29,9
(14) Удельное электросопротивление в мком/см при температуре в ° С:	
20	4,46
300	10
650 (твердый) (4)	15
650 (жидкий) (5)	26
1000	30

Key: (1). Designation of indices. (2). Indices. (3). Density in g/cm³ at temperature in °C. (4). solid. (5). liquid. (6). Melting point in °C. (7). Boiling point in °C. (8). Heat of fusion in cal/g. (9). Heat of vaporization in cal/g. (10). Heat of combustion in cal/mole. (11). Specific heat with 25°C V cal/g of °C. (12). Coefficient of thermal conductivity in cal/cm s of °C. (13). Coefficient of linear expansion $\alpha \cdot 10^{-6}$ in 1/°C at temperature in °C. (14). Specific resistance in mcal/cm at temperature in °C.

9. Physical properties of magnesium alloys.

(1) Наименование показателей	(2) Показатели по сплавам				
	МА3, МА5	МА2	ВМД3	ВМ65-1	МА9
Плотность при 20° С в Г/см³ (3)	1,82	1,78	1,83	1,80	1,77
Точка плавления в ° С (4)	600	615	627	649	618
Удельное электросопротивление при 20° С в мком/см (5)	16	11,5	10	–	12,5
Коэффициент теплопроводности при 20° С в кал/см · сек · ° С (6)	0,16	0,23	0,27	0,28	0,25
Коэффициент линейного расширения при 20—100° С α · 10⁻⁶ в 1/° С (7)	28	28	25,9	20,9	25,6
Удельная теплоемкость при 25° С в кал/г · ° С (8)	0,27	0,27	0,24	0,25	–

Key: (1). Designation of indices. (2). Indices on alloys. (3). Density with 20°C V g/cm³. (4). Melting point in °C. (5). Specific resistance with 20°C V μΩ/cm. (6). Coefficient of thermal conductivity with 20°C V cal/cm s of °C. (7). Coefficient of linear expansion with 20-100°C $\alpha \cdot 10^{-6}$ in 1/°C. (8). Specific heat with 25°C V cal/g of °C.

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10. Mechanical properties of semi-finished products from magnesium alloys with 20°C.

(1) Сплав	(2) Полуфабрикат	(3) Состояние поставки	$\sigma_в$ (4) в кГ/мм²		$\sigma_{0.2}$ (4) в кГ/мм²		(5) δ в %		(5) ψ в %	(9) $a_н$ в кГм/см²	σ_{-1} на базе $5\cdot10^7$ циклов (10)	(11) Сжатие		(12) Кручение		(13) Срез
			Направление вырезки образца (6)													
			(7) вдоль	(8) поперек	(7) вдоль	(8) поперек	(7) вдоль	(8) поперек				$\sigma_{-в}$	$\sigma_{-0.2}$	$\tau_{0.3}$	$\tau_в$	$\tau_{ср}$
											в кГ/мм²					
MA2	Пруток (14)	(18) Горячепрессованный	28	—	18	—	10	—	30	1.2	10.0	40	11	6	19	16
MA2-1	Пруток (14) ∅ 260 мм				19.5				—	—	—	—	—	—	—	—
	Плита 30 мм (15)		26	27	15	17	12	12	20	0.8	10.5	39	8.5	6	17.5	15
MA3	Пруток (14)		30	20	24	12		3	—	0.7	—	—		—	—	—
	Полоса (16)		27		17		14		23	1.0	11.0	42	—	6.5	19	14
MA5	Пруток (14) ∅ 260 мм		26.5		21.5		7		—		—	—		—	—	—
	Пруток (14)	(19) Закаленный	32	—	22	—	8	—	20	—	14	46	14	6.5	21	18
MA8	Пруток (14) ∅ до (17) 130 мм	(20) Горячепрессованный	26		15		7		—		—	—		—	—	—
	Полоса (16)				16		10			1.0	8.0		—	6	19	
MA9	Пруток (14) ∅ до (17) 130 мм		27		24				11	0.6	—	34		—	—	
ВМ65-1	Пруток (14) ∅: 112 мм	(21) Искусственно состаренный	31	27	28	12.5	12	14	24	0.9	15	47		12.5	23	16
	(17) до 100 мм		35	29	30	17.3	9	11			12		12.8		23.5	
	(17) до 260 мм		31	—	23	—	14	—	—	—	—	—	—	—	—	—
	Полоса (16) 34 мм		33	26	28	20	10	14	25	0.7	13	46	16			14

Key: (1). Alloy. (2). Semi-finished product. (3). As-received condition. (4). in kg/mm². (5). in %. (6). Direction of cut of sample/specimen. (7). lengthwise. (8). across. (9). in kg-m/cm². (10). on base of cycles. (11). Compression. (12). Torsion. (13). Shear/section. (14). Rod. (15). Plate/slab. (16). Band. (17). to. (18). Hot-pressed. (19). Hardened/tempered. (20). Hot-pressed. (21). Artificially aged.

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11. Mechanical properties of semi-finished products from magnesium alloys at different temperatures.

(1) Температура нагрева в °C	(2) МА2-1 горячекатаная плита 30 мм			(4) МА3 отожженная полоса			(6) МА5 пруток (закалка + старение)			(7) МА8 пруток			(7) МА9 пруток			(8) МА10 пруток ⌀ 25 мм (закалка + старение)			(9) ВМ65-1 полоса (старение)			(10) ВМ65-1 штамповки весом 80 кг		
	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ	$\sigma_в$	$\sigma_{0.2}$	δ
	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %	(3) в кГ/мм²		(5) в %
20	26	15	12	27	17	14	32	22	8	26	15	7	27	24	10	44	32	4	33	28	10	29	22	16
100	23	12	20	26.5	16	21			20	—	—	—	20	16	—	37	23	8	26	—	20	24	—	41
125	21	11	24	—	—	—	28	19	26				—	—		18.5	9.5	33	23.5		22	20		52
150	20	10	29	19	10.5	35	23	15	41	15	8	30	16	13	7	26	17	16	21		28	17		66
175	16.7	8.7	29.5	17.6	9	39	20	13	43	14	7.5	32	—	—	—	—	—	—	18		42	14		73
200	14	7.5	30	15	8	65	15	10	45	13	7	34	15	12	24	20	14	17	15		55	13		59
250	9	5	32	11.5	4.5	70	10	6	85	11	6	38	12	5	29	15	9.5	18	10		80	—		—
300	7	4	40	—	—	—	6.5	3.5	120	—	—	—	—	—	—	11	6.5	20	7		62			

Key: (1). Temperature of heating in °C. (2). MA2-1 hot-rolled plate/slab 30 mm. (3). in kg/mm². (4). MA3 annealed band. (5). in %. (6). MA5 rod (hardening + aging). (7). MA8 rod. (8). MA10 rod ⌀ of 25 mm (hardening + aging). (9). BM65-1 band (aging). (10). BM65-1 stamping with weight of 80 kg.

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In comparison with the aluminum ones magnesium alloys give considerably larger shrinkage and possess lower thermal conductivity.

During the construction of parts and assemblies should be avoided sharp/acute cuts and sharp transitions/transfers of sections/cuts. It is expedient to consider the anisotropy of the mechanical properties of forgings and stampings, so that the action of maximum stresses/voltages in the parts would coincide with the direction of the maximum mechanical properties of stampings.

With the connection of parts from the magnesium alloys with the parts from other materials it is necessary to consider the possibility of contact corrosion, while with the connection with the nonmetallic materials - aggressiveness of the latter.

Some magnesium alloys (MA3, MA5) being deformed to attackable under the stress (corrosion cracking).

The nonobservance of the temperature of the end of the forging and stamping (at too high a temperature of the end of the strain) leads to the formation of the large-grain structure and reduction/descent in the mechanical properties or (at too low a temperature of the end of the strain) to over-riveting and cracks. The results of statistical processing of the values of the mechanical properties of large-size series stampings from float BM65-1 are given in Fig. 27 in the form the normal distribution curves of the mechanical properties of stampings, manufactured on the hydraulic presses, moreover Fig. 27a gives results on ultimate strength, and in Fig. 27b for the values of elongation per unit length. A limit of the strength of analogous in the form of parts, but differing in the weight during the investigation three weight groups (I group to 30 kg, the II group from 31 to 100 kg and the III group - from 101 to 250 kg) virtually have the close values of ultimate strength with the small advantage in parts of the I group and minimum in the III group; the level of the values of the mechanical properties of the II group occupies intermediate position. The characteristics of the elongation per unit length, investigated on all three weight groups of parts, change with the same law, i.e., value relative to elongation of I group 16%, II group 12%, and III group 10%.

The obtained dependence of the values of the limit of strength and elongation per unit length is explained by the smaller degree of

the metal deformation in stampings of large weight. On structural strength of the loaded parts, manufactured from the stampings, great effect exerts the character of the arrangement of filament over the section/cut of stamping, determined from the macrostructure.

Fig. 28 gives the photograph of the general view of stamping, while in the photographs, located more to the right, its macrostructure in zones A and B, which is characterized by the normal arrangement of filament corresponding to the configuration of part. This macrostructure is characteristic for the stampings, manufactured with the reduced machining allowances.

12. Typical mechanical properties of forgings from the magnesium alloys with 20°C [1].

FOOTNOTE [1]. The mechanical properties of forgings depend on the arrangement of sample/specimen (explosive) relative to the direction of the metal during the deformation. The highest mechanical properties have samples/specimens, whose axis/axle is parallel to the direction of the maximum flow of material, i.e., most frequently along the length of forging, property on the width of forging somewhat less, and on the thickness - minimum

(1) Сплав	(2) Состояние поставки	$\sigma_в$ (4) в кГ/мм²	$\sigma_{0.2}$ (4) в кГ/мм²	δ в % (3)
МА1	(5) Без термообработки	19	—	6
МА2		27	16	10
МА2-1		28	—	
МА3	(6) Отжиг 340° 3 ч	30	22	12
МА5	Закалка (6a)	31	24	10
МА8	(7) Без термообработки	22	16	8
ВМ65-1	(8) Искусственное старение	31	25	12

Key: (1). Alloy. (2). As-received condition. (3). δ in %. (4). in kg/mm². (5). Without heat treatment. (6). Annealing of 340° 3 h. (6a). Hardening. (7). Without heat treatment. (8). Artificial aging.

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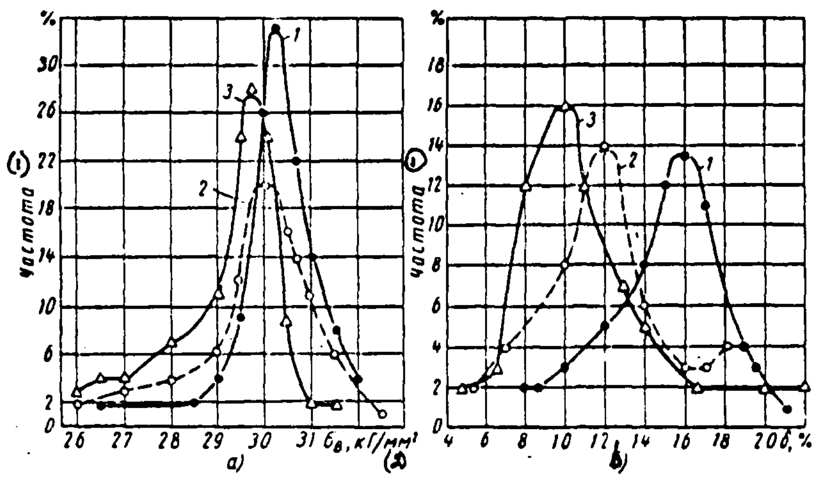

Fig. 27. Key: (1). Frequency. (2). kg/mm².

13. Typical mechanical properties of stampings from the magnesium alloys with 20°C.

(1) Сплав	(2) Полуфабрикаты в состоянии поставки	$\sigma_в$ (3) в кГ/мм²	$\sigma_{0,2}$ (3) в кГ/мм²	(4) δ в %	(5) σ_{-1} в кГ/мм² на базе $5 \cdot 10^7$ циклов	(6) HB в кГ/мм²	$a_н$ в кГм/см² (7)
MA1	(8) Штамповка без термообработки	18	–	4	–	–	–
MA8		22	–	8	–	–	–
MA2		26	15	12	11,0	62—66	1,2—1,5
MA2-1		27	17	10	–	–	–
	(9) Штамповка весом 50 кг без термообработки	28	14	19	10,5	–	–
MA3	(10) Штамповка (2 кг) (отжиг 340° С — 3 ч)	29	24	12	12,0	66—70	0,7—1,0
MA5	(11) Штамповка — закаленная	30	22	7	–	–	–
	(9) Штамповка весом 50 кг без термообработки	28	21	10	14,0	66—72	0,4—0,6
	(12) Штамповка весом 50 кг (старение 185° — 24 ч)	30,5	22	7	12,0	–	–
ВМ65-1	(13) Штамповка весом до 2 кг состаренная	32	26	14	14,0	70—76	0,7—1,2
	(14) Штамповка весом 50 кг состаренная	29	22	16	12,0	–	–
ВМ17	(15) Штамповка (крыльчатка без термообработки)	26	16	10	8,0	–	0,4

Key: (1). Alloy. (2). Semi-finished products in as-received condition. (3). in kg/mm². (4). δ in %. (5). σ_{-1} at kg/mm² on base $5 \cdot 10^7$ of cycles. (6). HB in kg/mm². (7). in kgfm/cm². (8). Stamping without heat treatment. (9). Stamping with weight of 50 kg without heat treatment. (10). Stamping (2 kg) (annealing of 340°C - 3 c). (11). Stamping - hardened/tempered. (12). Stamping with weight of 50 kg (aging 185° - 24 h. (13). Stamping with weight of up to 2 kg aged. (14). Stamping with weight of 50 kg aged. (15). Stamping (impeller without heat treatment.

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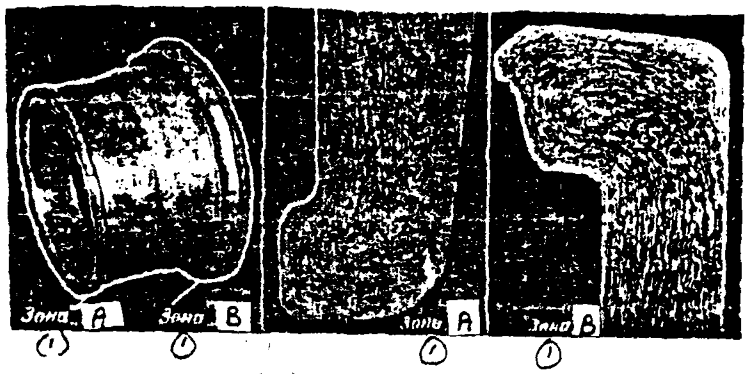

Fig. 28. Key: (1). Zone.

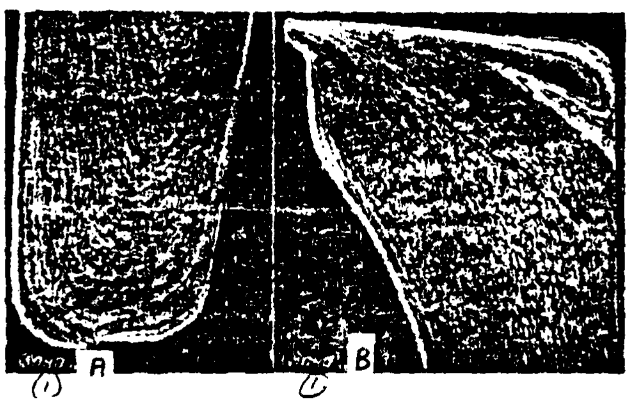

Fig. 29. Key: (1). Zone.

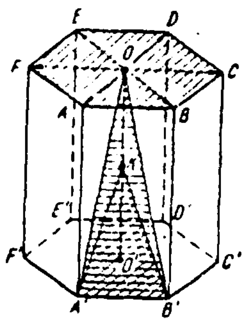

Fig. 30.

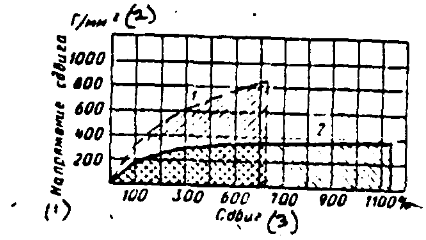

Fig. 31.

Fig. 30. Model of crystal lattice of magnesium and reference planes and direction of slip: ABCDE - basal plane (0001); OB - direction of slip; A'OB' - plane of pyramid of first first-order kind (1011); A'KB' - plane of pyramid of first kind second order (1012); OO' - hexagonal axis/axle.

Fig. 31. Curved strains/work hardenings of single crystal of magnesium with temperature of 250°C and at different deformation rates.

Key: (1). Shear stress. (2). G/mm². (3). Shift/shear.

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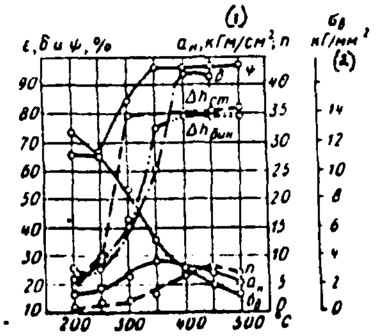

Fig. 32.

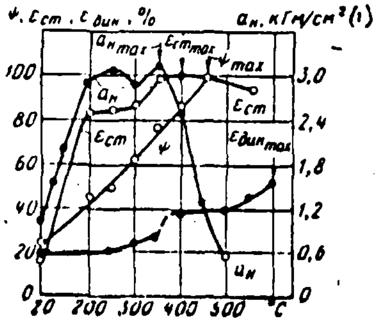

Fig. 33.

Fig. 32. Diagram of plasticity of alloy MA8.

Key: (1). kgfm/cm²; p. (2). kg/mm².

Fig. 33. Diagram of plasticity of alloy MA2.

Key: (1). kgfm/cm².

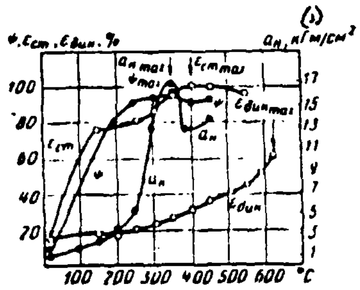

Fig. 34.

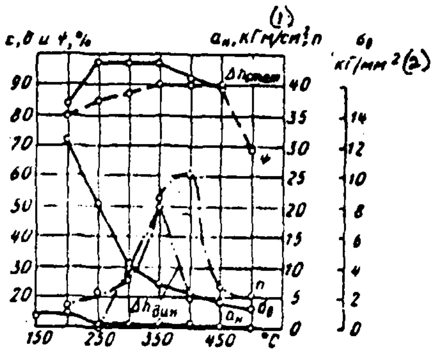

Fig. 35.

Fig. 34. Diagram of plasticity of alloy MA3.

Key: (1). kgfm/cm².

Fig. 35. Diagram of plasticity of alloy BM65-1.

Key: (1). kgfm/cm²; p. (2). kg/mm².

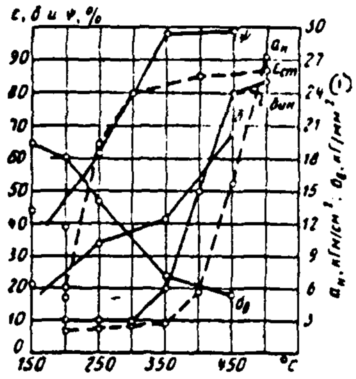

Fig. 36.

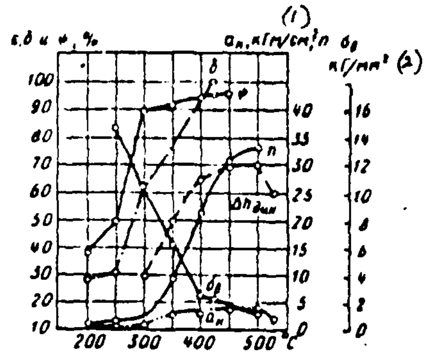

Fig. 37.

Fig. 36. Diagram of plasticity of alloy of type ВМД3.

Key: (1). kgfm/cm²; ..., kg/mm².

Fig. 37. Diagram of plasticity of alloy ВМ17.

Key: (1). kgfm/cm²; p. (2). kg/mm².

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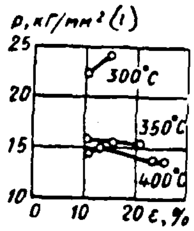

Fig. 38.

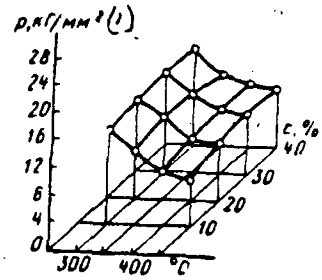

Fig. 39.

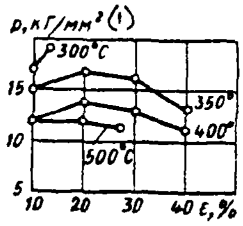

Fig. 40.

Fig. 38. Specific pressures of alloy MA1 with dynamic load (V_0=4.4-8.5 m/s).

Key: (1). kg/mm².

Fig. 39. Specific pressures of alloy MA8 with dynamic load (F. I. Filatov).

Key: (1). kg/mm².

Fig. 40. Specific pressures of alloy BM65-1 during dynamic deformation (F. I. Filatov).

Key: (1). kg/mm².

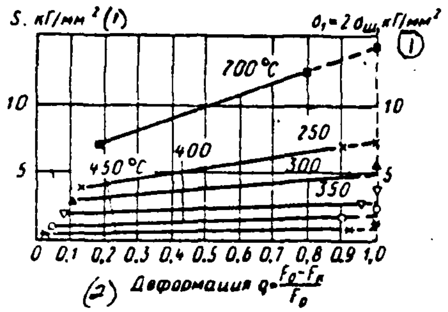

Fig. 41.

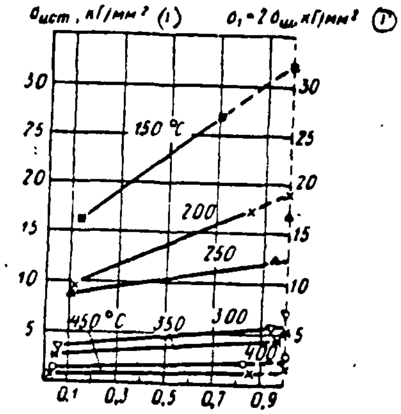

Fig. 42.

Fig. 41. Tentative straight line actual stresses of magnesium.

Key: (1). kg/mm². (2). Strain.

Fig. 42. Tentative straight line actual stresses of alloy MA3 (S. I. Gubkin, Ye. M. Sovitskiy).

Key: (1). kg/mm². (2). Strain.

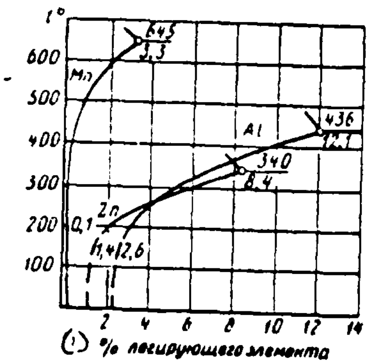

Fig. 43.

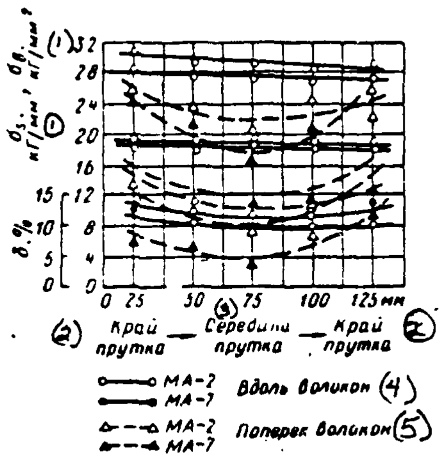

Fig. 44.

Fig. 43. Region of solid solutions in systems.

Key: (1). % the alloying element.

Fig. 44. Distribution of mechanical properties over section/cut of rod with general/common/total degree of strain 75% (A. A. Lukonin).

Key: (1). kg/mm². (2). Kray rod. (3). Middle of rod. (4). Along filaments. (5). Across filaments.

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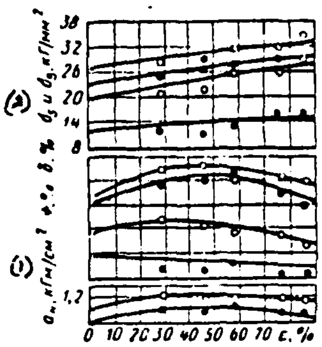

Fig. 45.

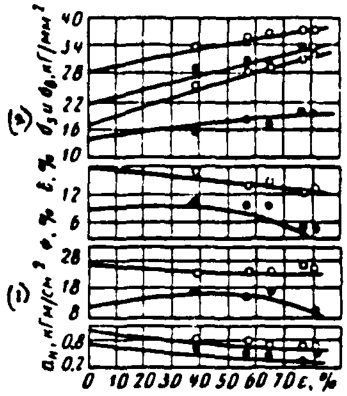

Fig. 46.

Fig. 45. Change in mechanical properties of alloy MA2 in dependence on degree of strain during forging in form-shaping dies of press (A. A. Lukonin).

Key: (1). kgfm/cm². (2). ... and ..., kg/mm².

Fig. 46. Change in mechanical properties of alloy MA3 in dependence on degree of strain during forging from degree of strain during forging in form-shaping dies of press (A. A. Lukonin): °-° along filament; ●-● across the grain.

Key: (1). kgfm/cm². (2). ... and ..., kg/mm².

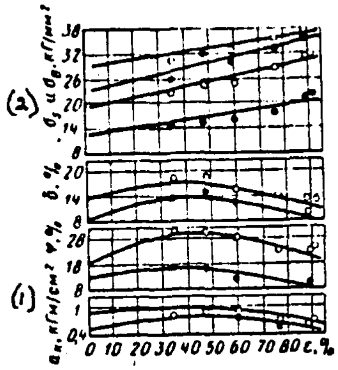

Fig. 47.

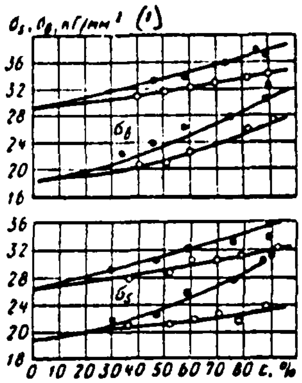

Fig. 48.

Fig. 47. Change in mechanical properties of alloy MA7 in dependence on degree of strain during forging in form-shaping dies of press (A. A. Lukonin).

Key: (1). kgfm/мм². (2). ... and ..., kg/mm².

Fig. 48. Change in mechanical properties of alloys MA2 and MA7 as a function of the degree of strain during forging on flat/plane °-° and figure faces ●-●.

Key: (1). kg/mm².

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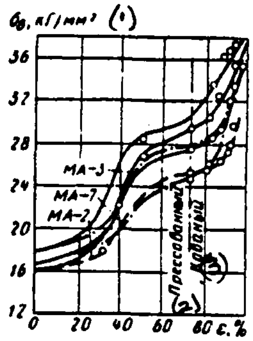

Fig. 49.

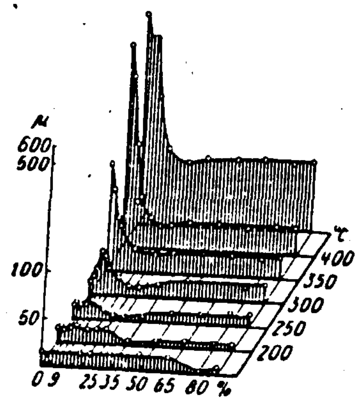

Fig. 50.

Fig 49. Change in tensile strength of magnesium alloys in dependence on degree of strain during extrusion/pressing and subsequent forging (A. A. Lukonin).

Key: (1). kg/mm². (2). Pressed. (3). Forged.

Fig. 50. Diagram of recrystallization of magnesium with settling on hydraulic press.

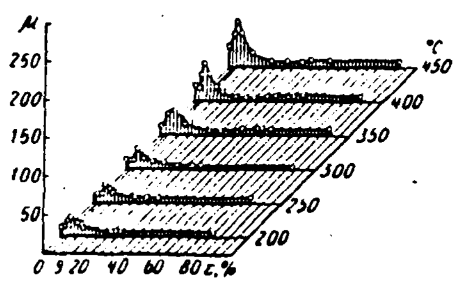

Fig. 51.

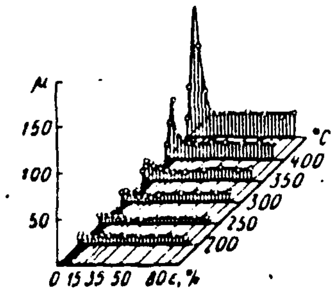

Fig. 52.

Fig. 51. Diagram of recrystallization of alloy MA2 with settling on hydraulic press.

Fig. 52. Diagram of recrystallization of alloy MA3 with settling on hydraulic press.

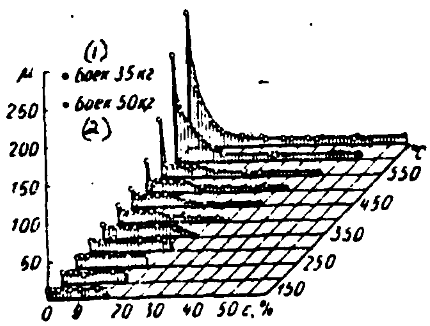

Fig. 53. Diagram of recrystallization of magnesium, deformed on vertical pile driver.

Key: (1). face 35 kg. (2). face 50 kg.

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Fig. 29 gives the macrostructure, observed on the templets (cut out from the same zones A and B, but from the stamping, manufactured on technology, which foresees large machining allowances), in which the character of the arrangement of filament does not correspond to the configuration of part. The parts, manufactured from the stampings with the larger allowances as a result of the unavoidable shearing of filament during the machining, have smaller structural strength, lowered/reduced reliability and service life of article.

The highest strength has the alloy BM65-1, at the same time its sufficiently high plastic properties give the possibility to carry out deformation both on the presses and on the hammers. Therefore alloy BM65-1 obtained the widest industrial use/application for the parts of different designation/purpose.

From the magnesium alloys, deformed by the method of forging and stamping, in the industry find wide application the alloys MA2, MA2-1, MA8. Alloys MA1, MA3 and MA5 are applied limited, alloys MA9, MA11, MA13, BMД1 and BM17 find use in the industry and they are utilized in accordance with their designation/purpose for

manufacturing parts which work under the overheat conditions.

With the connection of parts from the magnesium alloys with the parts from other materials it is necessary to consider the possibility of contact corrosion, while with the connection with the nonmetallic materials - aggressiveness of the latter.

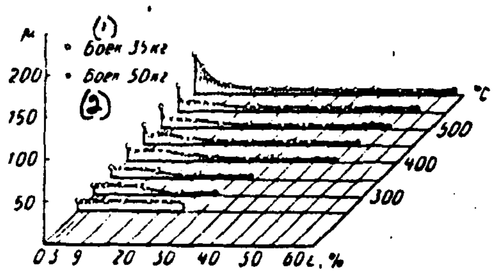

Fig. 54. Diagram of the recrystallization of the alloy MA3, deformed on the pile driver.

Key: (1). face 35 kg. (2). face 50 kg.

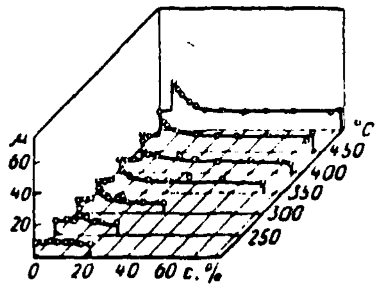

Fig. 55.

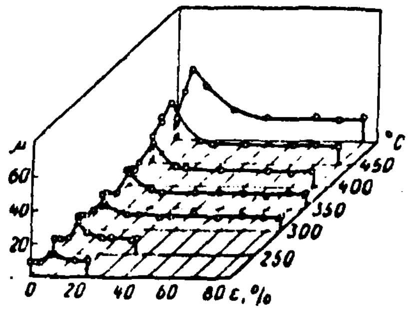

Fig. 56.

Fig. 55. Diagram of recrystallization of alloy MA8 with settling on press.

Fig. 56. Diagram of recrystallization of alloy MA8, deformed on pile driver.

14. Hardness, stampings from the alloys MA2 and MA3, manufactured on the friction press.

(1) Сплав	HB в кГ/мм² (2)	
	Стержень детали (3)	(4) Головка детали
МА2	65,5 65,5 62,4	64,3 65,1 63,8
МА3	68,5 66,5 68,6	66,4 67 1 65,5

Key: (1). Alloy. (2). NV in kg/mm². (3). Rod of part. (4). Head of part.

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Some magnesium alloys (MA3, MA5) being deformed udergo corrosion under stress (corrosion cracking).

Titanium alloys.

Data about the chemical composition, the physical and mechanical properties are cited in Tables 15-27 and 57-81 [1].

FOOTNOTE Figs. 61-67 initial state - preliminarily deformed. ENDFOOTNOTE.

Depending on designation/purpose and strength at a room temperature titanium alloys are divided into following groups.

The malleable alloys of the low strength (not more than 60 kg/mm^2) commercial titanium BT1-0, BT1-1, BT1-00 and dilute alloy OT4-1. These alloys are applied for manufacturing the parts of complex configuration, which do not test/experience large loads. Alloys are suitable for sheet stamping.

The malleable alloys of average/mean strength (60-100 kg/mm^2): medium-alloyed titanium alloys OT4, BT4, alloys BT6 and BT6C, and also alloys with an α-structure BT5-1 and BT5. They possess satisfactory technological plasticity and them are applied in the constructions/designs without the strengthened/hardened heat treatment. Alloy OT4 found the greatest use/application for manufacturing of forgings and stampings. Alloys BT5 and BT6 are applied when the moderate heat resistance with the satisfactory weldability is required.

The high-strength alloys being deformed: a) with ultimate strength are above 100 kg/mm^2: BT14 and BT20 and the experimental alloys BT15, BT16, which apply in the heat-treated state; b) alloy OT4-2 with ultimate strength in the annealed state $\sigma_e = 85 \div 120$ kg/mm^2 (by heat treatment it is not strengthened). Alloys BT14 and BT16 are

two-phase, while alloys BT15 and BT20 single-phase.

The plasticity of alloy BT14 during the hot working by pressure is satisfactory. Alloys BT15 and BT20 during the working by pressure are less plastic in comparison with the alloy BT14. The plasticity of alloy OT4-2 during the working by pressure is analogous to alloy BT14.

High-temperature (strength) titanium alloys being deformed: BT3-1, BT8, BT9 and BT18. The first three alloys have two-phase ($\alpha+\beta$)-structure, and alloy BT18 has single-phase α-structure at the basis. Alloys BT9 and BT18 possess a higher heat resistance. Allo BT3-1 is most widely used, it is applied mainly for the parts of the compressors of reaction engines. For the parts, which work at a temperature higher than 400°C, to preferably apply the alloy BT8, which possesses higher strength and thermal stability, than alloy BT3-1. Alloys BT3-1 and BT8 have satisfactory plasticity during the hot working by pressure.

Alloy BT18 has the lowered/reduced plasticity during the working by pressure in comparison with the alloys BT3-1 and BT8. The plasticity of alloy BT9 satisfactory; it it is possible to work by pressure (ductile, by rolling, by extrusion/pressing, etc.).

Copper alloys.

The data about the chemical composition, the physical and mechanical properties are cited in Table 28-37 and Fig. 82-95.

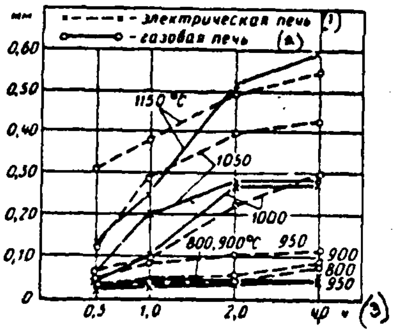

Fig. 57. Depth of the alpha-deposited layer of alloy BT8 depending on temperature and heating time.

Key: (1). electric furnace. (2). gas-fired furnace. (3). h.

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15. Chemical composition of titanium alloys.

(1) Сплав	(2) Легирующие элементы в %					(3) Примеси в % (не более)							(4) Прочие
	Al	Mn, Sn, Cr	V, Cr, Zr	Si	Fe, Nb	C	Fe	Si	Zr	O	N	H	
OT4—0	0.2—1.4	0.2—1.3 Mn							0.30				
OT4-1	0.7—2.2	0.5—1.8 Mn	—										
OT4	3.0—4.5	0.8—2.0 Mn							—	0.15		0.012	
OT4-2	5.5—7.0	1.0—2.3 Mn	0.5—2.5 Zr			0.10	0.30						
BT4	4.5—6.0	0.8—2.0 Mn	—	—	—			0.15	0.30				
BT5-1	4.0—6.0	2.0—3.0 Sn											
BT5	4.3—6.2									0.20			
BT6C	4.3—5.8	—	3.5—4.5 V			0.05	0.25			0.15	0.05	0.015	0.30
BT6	5.5—7.0		4.0—5.8 V				0.30		—				
BT3-1	5.2—6.8	2.0—3.0 Mo	1.0—2.5 Cr	0.15—0.40	0.2—0.7 Fe		—		0.50	0.18			
BT8	5.8—7.0	2.8—3.8 Mo	—	0.20—0.40			0.30	—		0.15			
BT9			0.8—2.5 Zr	0.20—0.35			0.25		—				
BT14	3.5—6.0	2.5—3.8 Mo	0.5—1.5 V		—	0.10	—		0.30				
BT15	2.3—3.6	6.8—8.0 Mo	9.5—11.0 Cr	—			0.30	0.15	—	0.12		0.012	
BT16	1.6—3.0	4.5—5.5 Mo	4.0—5.0 V				0.25		0.30				
BT18	7.2—8.2	0.2—1.0 Mo	10.0—12.0 Zr	0.05—0.18	0.5—1.5 Nb		0.20	—	—	0.15		0.015	
BT20	6.0—7.5	0.5—2.0 Mo	1.5—2.5 V	—	—		0.30	0.15					

Key: (1). Alloy. (2). Alloying elements in %. (3). Admixtures/impurities in % (not more than). (4). Other.

16. Physical properties of titanium.

16. Физические свойства титана

(1) Наименование показателей	(2) Показатели	(3) Наименование показателей	(2) Показатели
(4) Плотность в $г/см^3$	4.507	(11) Коэффициент теплопроводности (25°C) в кал/см · сек · °C	0.041
(5) Точка плавления в °C	1690	(12) Удельное электросопротивление (20°C) в мком · см	[illegible]
(6) Точка кипения в °C	3535	(13) Температура аллотропического превращения в °C периоды решетки в Å	[illegible]
(7) Теплота возгонки (25°C) в ккал	106.5	(14) α-титан, гексагональная плотноупакованная решетка, 25°C	[illegible]
(8) Удельная теплоемкость от 0 до 500°C в кал/г · °C	0.1386	(15) β-титан 900°C	[illegible]
(9) Энтропия (25°C) кал/моль · °C	7.24		
(10) Коэффициент линейного расширения (25°C) $\alpha \cdot 10^{-6}$ в 1/°C	8.5		

Key: (1). Designation of indices. (2). Indices. (3). Designation of indices. (4). Density in g/cm³. (5). Melting point in °C. (6). Boiling point in °C. (7). Heat of sublimation (25°C) in kcal. (8). Specific heat from 0 to 500°C V cal/g·°C. (9). Entropy (25°C) cal/mole·°C. (10). Coefficient of linear expansion (25°C) $\alpha \cdot 10^{-6}$ in 1/°C. (11). Coefficient of thermal conductivity (25°C) in cal/cm·s·°C. (12). Specific resistance (20°C) in $\mu\Omega$·cm. (13). Temperature of allotropic change in °C periods of grate in Å. (14). α-titanium, hexagonal close-packed lattice, 25°C. (15). β-titanium of 900°C.

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17. Physical properties of titanium alloys.

(1) Сплав	(2) Плотность γ в Г/см³	(3) Коэффициент линейного расширения α · 10⁻⁶ в 1/°C	(4) Коэффициент теплопроводности c в кал/см · сек · °C	(5) Удельное электросопротивление ρ в ом · мм²/м	(6) Теплоемкость C в кал/г · °C
ОТ4-1	4,55	8,0 (20—100); 8,6 (100—200); 9,4 (200—300); 0,6 (300—400); 9,6 (400—500)	0,023 (20); 0,025 (100); 0,029 (300); 0,032 (400); 0,035 (500); 0,030 (600)	—	—
ОТ4	4,55	8,0 (20—100); 8,6 (100—200); 9,1 (200—300); 9,0 (300—400); 9,4 (400—500); 9,8 (500—600)	0,023 (20)	—	—
ВТ4	4,6	8,4 (20); 9,0 (100—200); 9,0 (200—300); 9,0 (300—400)	0,020 (25); 0,022 (100); 0,025 (200); 0,028 (300); 0,081 (400)	—	0,125 (100); 0,135 (200); 0,145 (300); 0,100 (400)
ВТ5	4,4	8,3 (20—100); 8,9 (100—200); 9,5 (200—300); 10,4 (300—400); 10,6 (400—500); 10,8 (500—600)	0,021 (25), 0,023 (100), 0,025 (200); 0,027 (300); 0,030 (400); 0,034 (500); 0,037 (600); 0,04 (700); 0,043 (800); 0,047 (900)	1,08 (20), 1,15 (200), 1,18 (300); 1,2 (500)	0,13 (100); 0,14 (200); 0,15 (300); 0,16 (400); 0,17 (500); 0,18 (600)
ВТ6-1	4,42	8,3 (20—100); 8,9 (20—200); 9,1 (20—300); 9,3 (20—400); 9,5 (20—500); 9,6 (20—600); 9,8 (20—700); 10,1 (20—800); 10,5 (20—900)	0,021 (25); 0,023 (100); 0,026 (200); 0,029 (300); 0,032 (400); 0,035 (500); 0,038 (600); 0,041 (700); 0,044 (800)	1,38 (20)	0,12 (100); 0,13 (200); 0,135 (300); 0,14 (400); 0,15 (500); 0,16 (600); 0,17 (700); 0,19 (800)
ВТ3-1	4,5	8,6 (20—100); 11,6 (400—500)	0,019 (25); 0,02 (100); 0,024 (200); 0,027 (300); 0,037 (600); 0,040 (700)	1,36 (20)	0,11 (100); 0,12 (200); 0,13 (300); 0,15 (400); 0,16 (500); 0,17 (600)
ВТ8	4,48	8,3 (20—100); 8,6 (20—200); 8,7 (20—300); 8,8 (20—400); 9,0 (20—500); 9,1 (20—600)	0,017 (25); 0,020 (100); 0,023 (200); 0,027 (300); 0,030 (400); 0,034 (500); 0,037 (600)	1,61 (25)	0,12 (100)

Continue 17.

BT9	4,51	8,3 (20—100); 8,93 (20—200); 9,13 (20—300); 9,28 (20—400); 9,5 (20—500); 9,6 (20—600)	0,018 (25); 0,020 (100); 0,023 (200); 0,026 (300); 0,029 (400); 0,033 (500); 0,036 (600); 0,039 (700); 0,043 (800); 0,047 (900)	1,61 (20)	0,13 (100)
BT18	4,49	9,0 (20—100); 9,3 (20—200); 9,5 (20—300); 9,8 (20—400), 10,0 (20—500); 10,2 (20—600); 10,4 (20—700); 10,7 (20—800); 10,9 (20—900)	0,017 (25); 0,019 (100); 0,023 (200); 0,026 (300); 0,029 (400); 0,033 (500); 0,037 (600); 0,040 (700); 0,044 (800); 0,046 (900)	1,76 (20)	0,12 (100); 0,13 (200); 0,14 (300); 0,16 (400); 0,17 (500); 0,18 (600); 0,19 (700); 0,20 (800); 0,21 (900)
BT6	4,43	8,41 (20—100); 8,86 (100—200); 10,1 (200—300); 10,12 (300—400)	0,020 (25); 0,022 (100); 0,025 (200); 0,027 (300); 0,030 (400); 0,033 (500); 0,037 (600); 0,040 (700)	1,0 (20); 1,82 (200), 2,02 (400); 2,12 (600); 2,14 (700); 2,14 (800)	0,13 (100); 0,14 (200); 0,18 (300); 0,17 (400); 0,19 (500); 0,2 (600)
BT14	4,52	8 (20—100); 8,2 (20—200); 8,5 (20—300); 8,8 (20—400); 8,9 (20—500); 8,7 (20—600); 8,8 (20—700); 9,1 (20—800); 8,6 (20—900)	0,020 (25); 0,022 (100); 0,025 (200); 0,028 (300); 0,031 (400); 0,033 (500); 0,037 (600); 0,040 (700); 0,044 (800); 0,048 (900)	—	0,12 (100); 0,13 (200); 0,14 (300); 0,15 (400); 0,16 (500); 0,17 (600); 0,20 (700); 0,24 (800)
BT20	4,45	8 (20—100); 8,2 (20—200); 8,5 (20—300); 8,8 (20—400); 8,9 (20—500); 8,7 (20—600); 8,8 (20—700); 9,1 (20—800); 8,6 (20—900)	0,021 (100); 0,024 (200); 0,026 (300); 0,029 (400); 0,033 (500); 0,036 (600); 0,040 (700); 0,043 (800); 0,047 (900)	1,03	0,13 (100); 0,14 (200); 0,15 (300); 0,16 (400); 0,17 (500); 0,18 (600); 0,20 (700); 0,21 (800); 0,22 (900)
OT4-2	4,40	7,7 (20—100); 8,3 (100—200); 8,8 (200—300); 9,2 (500—600) 9,3 (300—400); 9,6 (400—500);	0,017 (25); 0,020 (100); 0,023 (200); 0,028 (300); 0,032 (400); 0,036 (500); 0,040 (600); 0,043 (700); 0,046 (900)	—	0,10 (100); 0,115 (200); 0,13 (300); 0,15 (400); 0,17 (500); 0,18 (600); 0,20 (700); 0,21 (800); 0,23 (900)

In the brackets is indicated the temperature of testing in °C.

Key: (1). Alloy. (2). Density γ in g/cm³. (3). Coefficient of linear expansion $\alpha \cdot 10^{-6}$ in 1/°C. (4). Coefficient of thermal conductivity c in cal/cm·s·°C. (5). Specific resistance ρ in $\Omega \cdot mm^2/m$. (6). Heat capacity C in cal/g·°C.

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18. Possible strain/work hardening of titanium alloys by oxygen and by carbon.

(1) Элемент	(2) Содержание в %	(3) Повышение предела прочности в кГ/мм² на
(4) Кислород		6,0
(5) Азот	0,05	12,5
(6) Углерод		8,5

Key: (1). Element/cell. (2). Content in %. (3). Increase in ultimate strength in kg/mm² on. (4). Oxygen. (5). Nitrogen. (6). Carbon.

19. Mechanical properties of forgings and stampings from titanium alloys at a normal temperature.

(1) Сплав	(2) $\sigma_в$ в кГ/мм²	δ	ψ	(3) $a_н$ в кГм/см²
		(3) в %		
(4) Поковки, штамповки и прутки кованые диаметром до 100 мм отожженные				
ВТ1-0	45—60	—	45,0	7
ОТ4-0	60—75	15	35,0	4,5
ОТ4	70—90			
ВТ4	85—105		30,0	3,5
ВТ5	75—95	10		3,0
ВТ5-1	80—100		25,0	4,0
ВТ6	95—110		30,0	3,0
ВТ14	90		35,0	5,0
(5) Диски и кольца, штампованные и кованые отожженные				
ВТ14	85	8	25,0	4,0
(6) Прутки прессованные диаметром до 100 мм отожженные				
ВТ14	90	10	35,0	5,0
(7) Прутки прессованные диаметром до 100 мм закаленные и состаренные				
ВТ14	110	4	8	2
(8) Прутки и поковки диаметром 100 мм закаленные				
ВТ15	90	12	—	4,0
(9) Прутки и поковки закаленные и состаренные				
ВТ15	135	4	—	—
(10) Прутки диаметром 10—80 мм отожженные				
ВТ16	90—100	12	40,0	—
(11) Прутки диаметром 10—100 мм закаленные и состаренные				
ВТ16	105—125	5	20,0	—
(12) Штамповки, поковки и кованые прутки диаметром до 100 мм после изотермического отжига при 870—650 °С, охлаждаемые на воздухе				
ОТ4-2	95—100	8	25,0	—
ВТ3-1	100	10	25,0	3
(13) Прутки кованые диаметром более 100 мм после изотермического отжига при 870—650° С, охлаждаемые на воздухе				
ВТ3-1	90	8	20,0	3
(14) Диски и кольца				
ВТ3-1	90	8	20,0	3
ВТ3-1	100	10	30,0	3
(15) Поковки, штамповки, прутки кованые отожженные				
ВТ8	105	9	30,0	3
(16) Заготовки для изготовления лопаток отожженные				
ВТ8	105	9	30,0	3
(17) Прутки, полосы, поковки, штамповки отожженные				
ВТ9	105	9	25,0	3
(18) Прутки, полосы, поковки, штамповки отожженные				
ВТ18	95	8	20,0	2

Key: (1). Alloy. (2). ... in kg/mm^2. (3). in %. (4). ... in $kgfm/cm^2$. (4). Forgings, stamping and rods forged with diameter to 100 mm annealed. (5). Disks and ring, stamped/die-forged and forged annealed. (6). Rods pressed by diameter to 100 mm annealed. (7). Rods pressed by diameter to 100 mm hardened/tempered and aged. (8). Rods and forging with diameter of 100 mm hardened/tempered. (9). Rods and forging, hardened/tempered and aged. (10). Rods with diameter of 10-20 mm annealed. (11). Rods with diameter of 10-100 mm hardened/tempered and aged. (12). Stampings, forging and forged rods with diameter of up to 100 mm after isothermal annealing with 870-650°C, cooled in air. (13). Rods forged with diameter are more than 100 mm after isothermal annealing with 870-650°C, cooled in air. (14). Disks and ring. (15). Forgings, stamping, rods forged annealed. (16). Blanks for manufacturing blades annealed. (17). Rods, band, forging, stamping annealed. (18). Rods, band, forging, stamping annealed.

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FOOTNOTE [1]. Hardened/tempered and aged with respect to 115; 6; 20; 2.5. ENDFOOTNOTE.

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20. Mechanical properties of forged (according to AMTU [AMTY - Aviation Metallurgical Technical Specifications] 531-67) and pressed rods at normal temperature by diameter or by side of square from 65 to 100 mm.

(1) Сплав	$\sigma_в$ в кГ/мм² (2)	δ (3) в %	ψ	$a_н$ в кГм/см² (3a)	(4) HB (диаметр отпечатка) (10/3000) в мм
ВТ1-00	30—45	25	55	12	4,9—5,5
ВТ1-0	40—55	20	50	10	4,7—5,2
ОТ4-0	50—65		45	7	3,8—4,3
ОТ4	70—90	10	30	4	3,5—4,0
ОТ4-1	60—75	15	35	4,5	3,8—4,2
ОТ4-2	95—110	8	25	3	3,3—3,7
ВТ4	85—105		30	3,5	3,4—3,8
ВТ3-1	100—120	10	25	3	3,3—3,7
ВТ5	75—95				3,4—3,9
ВТ5-1	80—100			4	3,4—3,8
ВТ6	92—107		30	3	3,3—3,7
		(5) факультативны			
ВТ6	110—125	6	20	2,5	3,1—3,4
ВТ6С	85—100	10	25	4	3,4—3,8
		(5) факультативны			
ВТ6С	105—120	6	20		3,2—3,4
ВТ8	100—120			3	
ВТ9	105—125	9	25		3,3—3,5
ВТ14	90—110	10	35	5	3,4—3,8
ВТ14	(6) не менее 110	4	8	2	3,5—3,4

Note. Samples/specimens for the testing were cut out lengthwise.

Key: (1). Alloy. (2). ... in kg/mm². (3). in %. (3a). ... in kgfm/cm². (4). HB (diameter of impression) (10/3000) in mm. (5). they are faculative. (6). not less than.

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FOOTNOTE [1,2]. As-received condition respectively: annealed; hardened/tempered and aged. ENDFOOTNOTE.

21. The mechanical properties of forged (annealed) rods at a normal temperature by diameter or by the side of square are more than 100 mm (according to AMTU 534-67).

(1) Сплав	$\sigma_в$ в кГ/мм² (2)	δ (3) в %	ψ (3) в %	$a_н$ в кГм/см² (3a)	(4) HB (диаметр отпечатка) (10:3000) в мм
BT1-00 [2]	27—45	27	36	6	4,9—5,5
BT1-00 [2]		25	34		
BT1-0 [2]	36—55	17	32,5	5	4,7—5,2
BT1-0 [3]		15	30		
OT4-0 [1]	45—65	17			3,6—4,3
OT4 •	65—90	8,5	20	3,5	3,5—4,0
OT4-1 [1]	55—75	12	23	4	3,6—4,2
OT4-2 [1]	90—110	7	20	3	3,3—3,7
BT4 •	80—105	8,5			3,4—3,8
BT3-1 [1]	95—120	8			3,3—3,7
BT5 •	73—95	6	16	5	3,4—3,9
BT5-1 [1]	76—100			4,5	3,4—3,8
BT6 •	85—107		20	3	3,3—3,7
BT6C [1]	77—100			4	3,4—3,8
BT8 [2]	95—120	7,5		3	3,3—3,5
BT8 [3]		7,0	16		
BT9 [2]	100—125	6	14		
BT9 [3]	95—125				
BT14 [2]	88—110	8,5	23	4,5	3,4—3,8
BT14 [3]	85—110	8	20	4	

Note. Samples/specimens for the testing were cut out in the transverse direction of filament.

Key: (1). Alloy. (2). ... in kg/mm². (3). in %. (3a). in kgfm/cm². (4). HB (diameter of impression) (10/3000) in mm.

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FOOTNOTE [1], [2], [3]. Diameter or the side of square respectively: 101-250; 101-150; 151-250 mm. ENDFOOTNOTE.

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22. Mechanical properties of rounds with diameter of up to 60 mm at normal temperature (on AMTU 451-67).

(1) Сплав	(2) $\sigma_в$ в кГ/мм²	(3) δ при $l = 5d$	ψ	(5) $a_н$ в кГм/см²	(6) HB (диаметр отпечатка) (10/3000) в мм
		(4) в % не менее			
BT1-00	30—45	25	55	12.0	4,9—5,5
BT1-0	40—55	20	50	10.0	4,7—5,2
OT4-0	50—65		45	7.0	3,6—4,3
OT4-1	60—75	15	35	4.5	3,8—4,2
OT4	70—90	11	30	4.0	3,5—4,0
OT4-2	90—105	8	25	3,0	3,3—3,7
BT4	85—105	10	30	3,5	3,4—3,8
BT3-1	100—102			3,0	3,3—3,7
BT3-1	(7) Не менее 120	6	20	2,0	3,0—3,3
BT5	75—95	10	25	5.0	3,4—3,9
BT5-1	80—100			4.0	3,4—3,8
BT6	92—107		30		3,3—3,7
BT6	(7) Не менее 110	6	20	2.5	3,1—3,4
BT6C	85—100	10	30	4.0	3,4—3,8
BT6C,	(7) Не менее 105	6	25	3,0	3,2—3,5
BT8	100—120	9	30		3,3—3,7
BT8	(7) Не менее 120	6	20	2.0	3,0—3,3
BT9	105—125	9	30	3.0	3,3—3,7
BT9	(7) Не менее 120	6	20	2.0	3,0—3,3
BT14	90—105	10	35	5.0	3,4—3,6
BT14	(7) Не менее 112	6	12	2.0	3,1—3,4
BT16	80—100	8	40	5,0	3,4—3,8
BT16	(7) Не менее 110	6	30	3,0	3,1—3,4

The note: samples/specimens for the testing were cut out lengthwise.

Key: (1). Alloy. (2). in kg/mm². (3). δ with l=5d. (4). in % not less. (5). in kgfm/cm². (6). HB (diameter of impression) (10/3000) in

mm. (7). not less

FOOTNOTE [1]. Annealed.

[2]. Hardened/tempered and aged. ENDFOOTNOTE.

23. Mechanical properties of stampings and flows with thickness to 100 mm.

(1) Сплав	(2) $\sigma_в$ в кГ/мм²	δ (3) в % не менее	ψ (3) в % не менее	(4) $a_н$ в кГм/см²	(5) HB (диаметр отпечатка 10/300) в мм
ВТ1-00 [1]	30—45	25	55	12	4,9—5,5
ВТ1-0 [1]	40—55	20	50	10	4,7—5,2
ОТ4-0 [1]	50—65		45	7	4,2—4,8
ОТ4-1 [1]	60—75	15	35	4,5	3,8—4,2
ОТ4 [1]	70—90	10	30	3,5	3,5—4,0
ОТ4-2 [1]	85—110	8	25	3	3,3—3,7
ВТ4 [1]	85—105		30	3,5	3,4—3,8
ВТ5 [1]	75—95	10	25	3	3,4—3,9
ВТ5-1 [1]	80—100			4	3,4—3,8
ВТ6 [1]	92—110			3	3,3—3,7
ВТ6 [2]	(6) Не менее 110	6	20	2,5	(6) Не менее 3,0
ВТ6С [1]	85—100	10	25	4	3,4—3,8
ВТ6С [2]	(6) Не менее 105	6	20	3	(6) Не менее 3,1
ВТ3-1 [1]	100—120	10	25		3,2—3,7
ВТ3-1 [2]	(6) Не менее 120	6	20	2	(6) Не менее 3,0
ВТ8 [1]	100—120	9	25	3	3,2—3,7
ВТ8 [2]	(6) Не менее 120	6	20	2	(6) Не менее 3,0
ВТ9 [1]	105—125	9	25	3	3,2—3,7
ВТ9 [2]	(6) Не менее 120	6	20	2	(6) Не менее 3,0
ВТ14 [1]	90—110	9	30	5	3,4—3,8
ВТ20 [1]	95—115	10	25	4	3,3—3,6
ВТ22 [1]	110—130	7	20	3	3,1—3,7

Note. Mechanical properties were determined in the samples/specimens with a diameter of 5 mm with the five-fold calculated length, cut out lengthwise of filament.

Key: (1). Alloy. (2). in kg/mm². (3). in % not less. (4). in kgfm/cm². (5). HB (diameter of impression 10/300) in mm. (6). not less.

FOOTNOTE [1]. Annealed.

[2]. Hardened/tempered and aged. ENDFOOTNOTE.

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24. Mechanical properties of annealed stampings and forgings with thickness are more than 100 mm.

(1) Сплав	(2) $\sigma_в$ в кГ/мм²	δ (3) в % не менее	ψ (3) в % не менее	(4) $a_н$ в кГм/см²	(5) HB (диаметр отпечатка 10/3000) в мм
ВТ1-00 [1]	27—45	21	36	6	4,9—5,5
ВТ1-00 [2]		19	34		
ВТ1-0 [1]	36—55	17	32,5	5	4,7—5,2
ВТ1-0 [2]		15	30		
ОТ4-0 [3]	45—65	17			4,2—4,8
ОТ4-1 [1]	55—75	12	23	4	3,6—4,2
ОТ4-1 [2]		10			
ОТ4 [3]	65—90	8,5	20	3,5	3,5—4,0
ОТ4-2 [3]	85—105	7		3	3,3—3,7
ВТ4 [3]	80—105	8,5			3,4—3,8
ВТ5 [3]	73—95	6	16	5	3,4—3,9
ВТ5-1 [3]	76—100			4,5	3,4—3,8
ВТ6 [3]	85—107		20	3	3,3—3,7
ВТ6С [3]	77—100			4	3,4—3,8
ВТ3-1 [3]	95—120	8		3	3,2—3,7
ВТ8 [2]		7	16		
ВТ8 [2]					
ВТ9 [1]	100—125	6	14		
ВТ9 [2]	95—125				
ВТ14 [1]	86—110	8	23	4,5	3,4—3,8
ВТ14 [2]	85—110		20	4	
ВТ20 [2]	90—115	6		3	3,3—3,7
ВТ22 [2]	110—130		14		3,1—3,7

Note. Mechanical properties were determined in the samples/specimens with a diameter of 5 mm with the five-fold calculated length, cut out in the transverse or chord fiber directions.

Key: (1). Alloy. (2). in kg/mm². (3). in % not less. (4). in kgfm/cm². (5). HB (diameter of impression 10/3000) in mm.

FOOTNOTE [1], [2], [3]. Thickness in mm with respect to 101-150; 151-250; 101-250. ENDFOOTNOTE.

25. Mechanical properties of annealed forgings of type of rings from titanium alloys.

(1) Сплав	(2) $\sigma_в$ в кГ/мм²	(3) δ при $l = 5d$	ψ	(4) $a_н$ в кГм/см²	(5) HB (диаметр отпечатка 10/3000) в мм
		в %			
ОТ4	67	10	25		3,5—4,0
ВТ3-1 ВТ8	95	6		3,0	3,2—3,7
ВТ9	100		20	2,5	
ВТ5 ВТ5-1	75	9		3,0	3,4—4,0 3,4—3,8
ВТ6	90		25		3,3—3,7
ВТ20		6	20		3,3—3,6

Note. Mechanical properties were determined in the samples/specimens with a diameter of 5 mm with the five-fold calculated length, cut out in the chord fiber direction.

Key: (1). Alloy. (2). in kg/mm². (3). δ with l=5d. (4). in kgfm/cm². (5). HB (diameter of impression 10/3000) in mm.

26. Mechanical properties of annealed stampings of type of disks.

(1) Сплав	(2) Вес штамповки в кг	(3) $\sigma_в$ в кГ/мм²	δ (4) в % не менее	ψ (4) в % не менее	(5) HB в кГ/мм²
ВТ3-1	(6) До 25	98	9	22	- -
	26—100	96		20	
	101—200	95			
ВТ6	(6) До 25	100	8	22	3
	26—50	96		20	
	51—100			18	
	101—200	95	6	16	
ВТ8	(6) До 25	105	8	22	
	25—50			20	
	51—100	103		18	25
	101—200	100	6	16	

Notes: 1. HB (diameter of impression 10/3000) for all samples/specimens is 3.2-3.7 mm.

2. Mechanical properties were determined in samples/specimens with diameter of 5 mm, with five-fold calculated length, cut out in chord fiber direction.

Key: (1). Alloy. (2). Weight of stamping in kg. (3). in kg/mm². (4). in % not less. (5). HB in kgfm/cm². (6). To.

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27. Mechanical properties of stampings of type of compressor blades.

(1) Сплав	(2) $\sigma_в$ в кГ/мм² (7) не менее	(3) δ при $l = 5d$ (6) в % (7) не менее	ψ (6) в % (7) не менее	(4) $a_н$ в кГм/см² (7) не менее	(5) HB (диаметр отпечатка 10/3000) в мм
ОТ4	70 [1]	10	30	3,5	3,5—4,0
ВТ3-1	100 [1]		25	3,0	3,2—3,7
	125 [2]	6	20	2,5	3,1—3,3
ВТ5	75 [1]	10	25	3,0	3,4—3,9
ВТ5-1	80 [1]			4,0	3,4—3,8
ВТ6	95 [1]		30	3,0	3,3—3,7
ВТ8	105 [1]	9			3,2—3,7
	120 [2]	6	20		3,1—3,3
ВТ9	105 [1]	9	25		3,2—3,7
	120 [2]	6	20	2,5	3,1—3,3
ВТ18	95 [1]	10	25	1,6	—

Note. Mechanical properties were determined in the samples/specimens with a diameter of 3 or 5 mm with the five-fold calculated length, cut out lengthwise of filament.

Key: (1). Alloy. (2). in kg/mm². (3). δ with l=5d. (4). in kgfm/cm². (5). HB (diameter of impression 10/3000) in mm. (6). in %. (7). not less.

FOOTNOTE [1], [2]. State of samples/specimens respectively: annealed; VTMO. ENDFOOTNOTE.

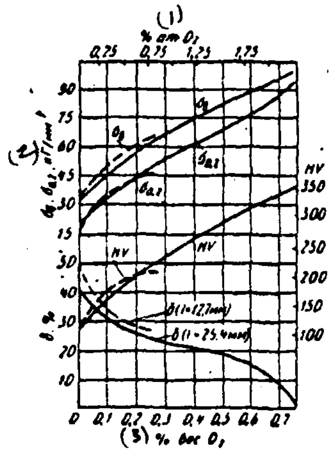

Fig. 58.

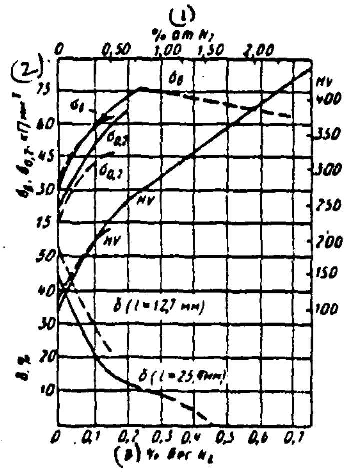

Fig. 59.

Fig. 58. Change in limit of strength, viscosity/yield and elongation in dependence on oxygen content in titanium.

Key: (1). % at. (2). kg/mm². (3). % weight.

Fig. 59. Change in limits of strength, viscosity/yield and elongation in dependence on content of nitrogen in titanium.

Key: (1). % at. (2). kg/mm². (3). % weight.

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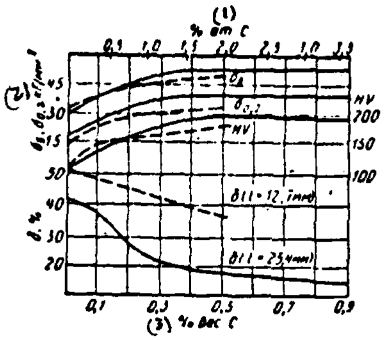

Fig. 60.

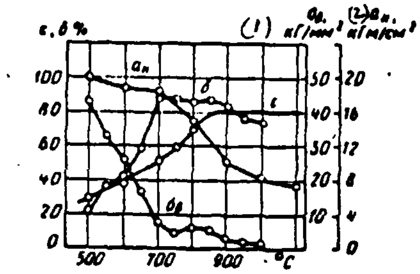

Fig. 61.

Fig. 60. Change in limits of strength, viscosity/yield and elongation in dependence on carbon content in titanium.

Key: (1). % at. (2). kg/mm². (3). % weight.

Fig. 61. Diagram of technological plasticity of alloy OT4.

Key: (1). kg/mm². (2). kgfm/cm².

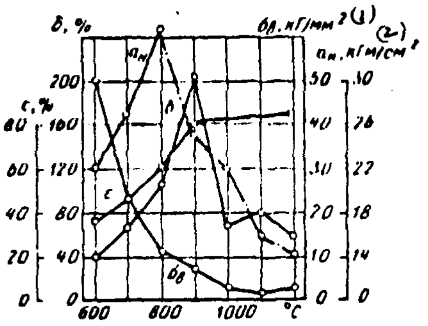

Fig. 62.

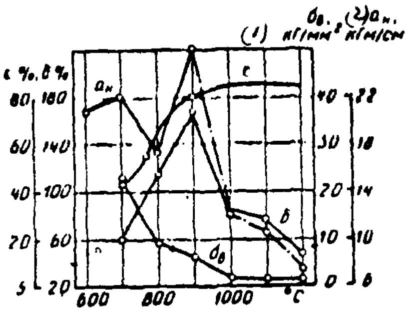

Fig. 63.

Fig. 62. Diagram of technological plasticity of alloy BT3-1.

Key: (1). kg/mm². (2). kgfm/cm².

Fig. 63. Diagram of technological plasticity of alloy BT5-1.

Key: (1). kg/mm². (2). kg-m/cm.

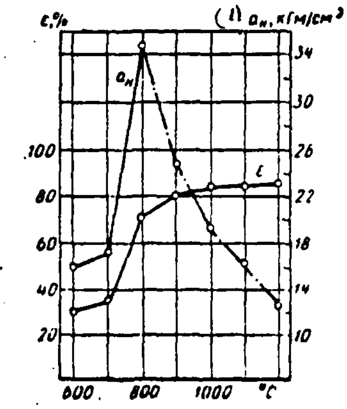

Fig. 64.

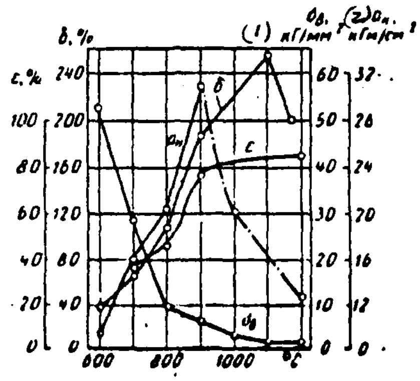

Fig. 65.

Fig. 64. Diagram of technological plasticity of alloy BT6.

Key: (1). kgfm/cm².

Fig. 65. Diagram of technological plasticity of alloy BT8.

Key: (1). kg/mm². (2). kgfm/cm².

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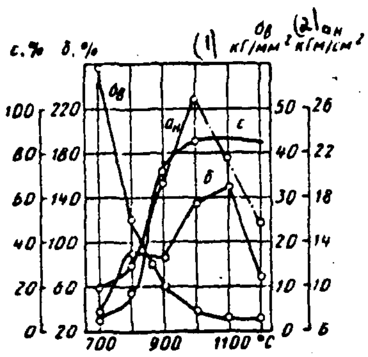

Fig. 66.

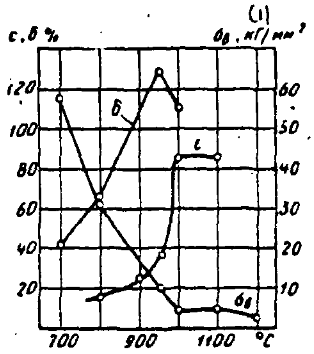

Fig. 67.

Fig. 66. Diagram of technological plasticity of alloy BT9.

Key: (1). kg/mm². (2). kgfm/cm².

Fig. 67. Diagram of technological plasticity of alloy BT18 (according to data of V. Ya. Kleymenov, T. N. Sazonova and V. M. Arzhakov).

Key: (1). kg/mm².

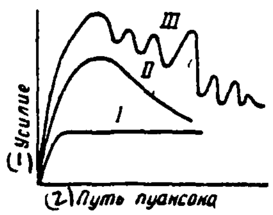

Fig. 68.

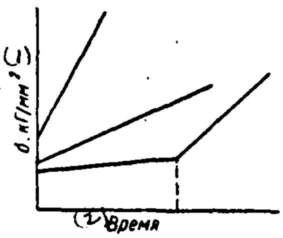

Fig. 69.

Fig. 68. Different types of curves of specific pressure of flow (N. S. Kurnakov, S. F. Zhemchuzhnyy).

Key: (1). Effort/force. (2). Way of male die/punch.

Fig. 69. Possible curves of specific pressure of flow for low-plasticity materials (N. I. Korneyev, I. G. Skugarev).

Key: (1). kg/mm². (2). Time.

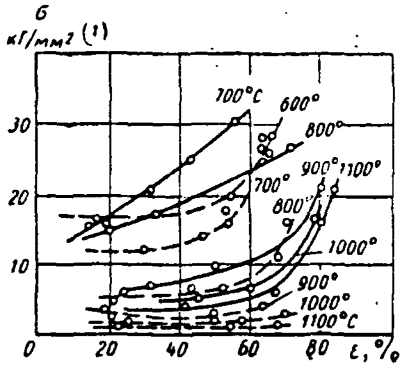

Fig. 70.

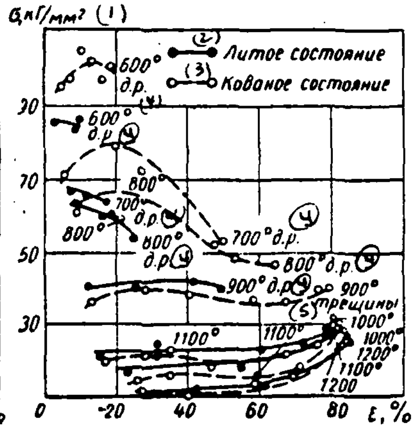

Fig. 71.

Fig. 70. Average/mean specific pressure for alloy BT1 (forged state): ----- dynamic deformation; - - - - static deformation.

Key: (1). kg/mm².

Fig. 71. Average/mean specific pressure of alloy BT3-1 in cast and forged states during dynamic deformation.

Key: (1). kg/mm². (2). Cast state. (3). Forged state. (4). d.r. (5). crack.

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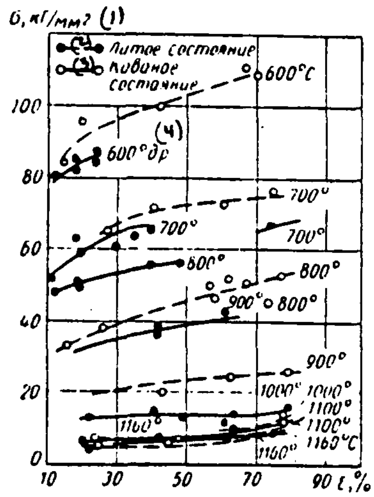

Fig. 72.

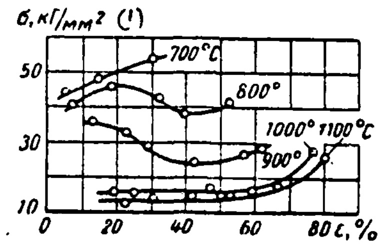

Fig. 73.

Fig. 72. Average/mean specific pressure of alloy BT3-1 in cast and forged states during static deformation.

Key: (1). kg/mm². (2). Cast state. (3). Forged state. (4). other.

Fig. 73. Average/mean specific pressures of alloy BT6 during dynamic deformation.

Key: (1). kg/mm².

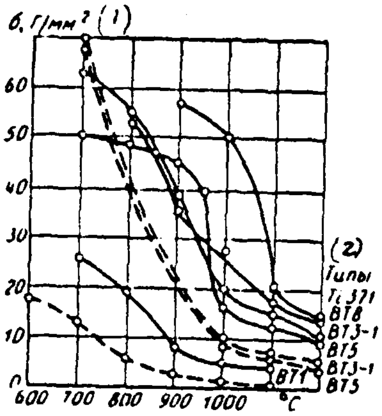

Fig. 74.

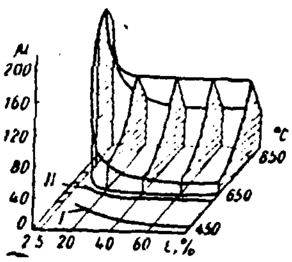

Fig. 75.

Fig. 74. Average/mean specific pressures of flow of titanium alloys during deformation on 40% depending on temperature (forged state): ------ dynamic deformation; - - - static deformation.

Key: (1). G/mm². (2). Types.

Fig. 75. Diagram of recrystallization of pure titanium: I - it began; II - end.

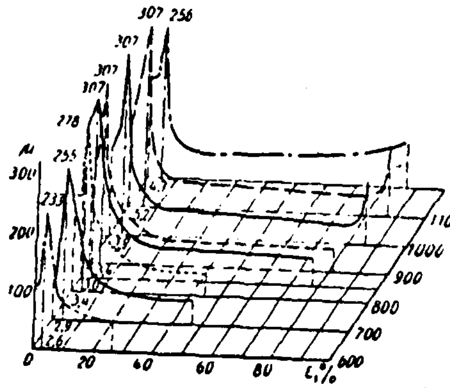

Fig. 76.

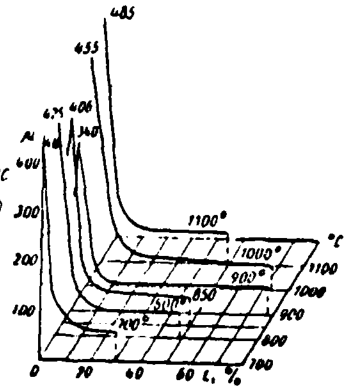

Fig. 77.

Fig. 76. Diagram of recrystallization of alloy of type BT3-1 (initial state preliminarily forged, needle microstructure).

Fig. 77. Diagram of recrystallization of alloy of type BT3-1 (initial state - cast).

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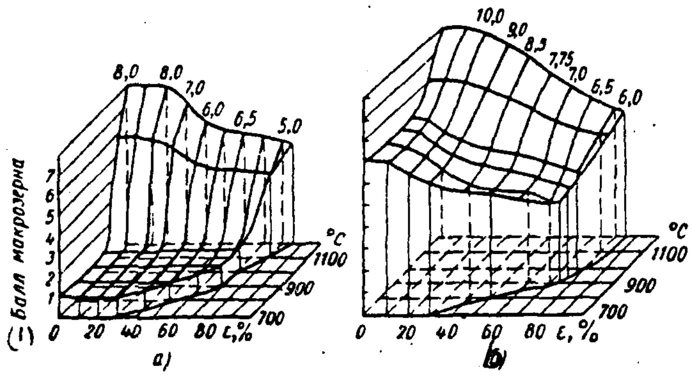

Fig. 78. Diagram of recrystallization of alloy BT3-1 (on macrograin): a) temperature of complete α+β⇄β-transformation of 990°C (initial structure equiaxial); b) temperature of complete α+β⇄β-transformation of 990°C (initial microstructure - needle α+β).

Key: the point of macrograin.

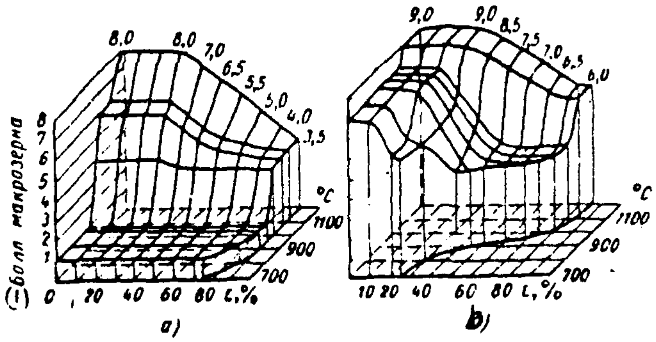

Fig. 79. Diagram of recrystallization of alloy BT8 (on macrograin): a) temperature of complete α+β⇄β-transformation of 980-1000° (initial microstructure equiaxial); b) temperature of complete α+β⇄β-transformation of 980-1000°C (initial microstructure needle).

Key: (1). Point of macrograin.

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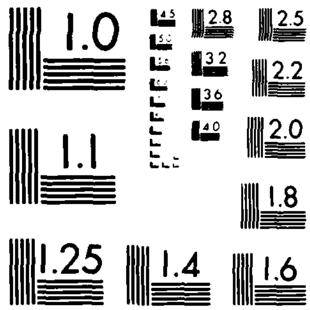
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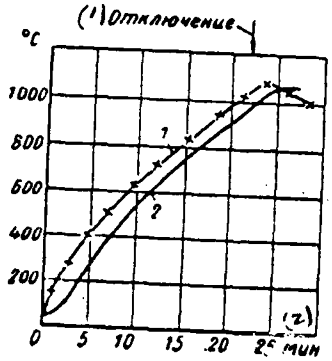

Fig. 80.

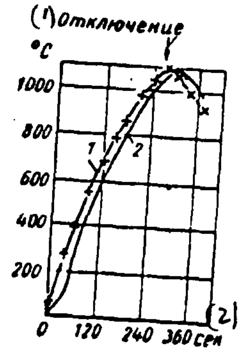

Fig. 81.

Fig. 80. heating blanks with diameter of 150 mm on industrial purity/finish in three-layered inductor: 1 - temperature of surface of blank; 2 - temperature of middle of blank.

Key: (1). Cutoff/disconnection. (2). min.

Fig. 81. Heating blanks with diameter of 55 mm at frequency of 2500 Hz: 1 - temperature of surface of blank; 2 - temperature of middle of blank.

Key: (1). Cutoff/disconnection. (2). s.

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28. Chemical composition of brass.

(1) Сплав	(2) Основные элементы в %		(3) Примеси в % не более						(4) Всего примесей
	Cu	Al, Si, Sn, Pb, Mn	Pb, Ni, Mn	Fe, Sn	Sb, Mn	Bi	P	Sn, As	
			(5) Простые (двойные) латуни						
Л96	95—97								0.20
Л90	88—91			0.10 Fe			0.01		
Л85	84—86				0.005 Sb	0,002		—	0.30
Л80	79—81		0.03 Pb						
Л75	75			0.2 Fe			—		
Л70	69—72	—		0.07 Fe	0.002 Sb		0.005	0.005 As	0.20
Л68	67—70			0.10 Fe	0.005 Sb		0.01		0.30
Л66	64.5—67.5		0.30 Pb	0.07 Fe	—	—	—	—	—
Л62	60.5—63.5		0.06 Pb	0.15 Fe	0.005 Sb	0.002	0.01		0.5
Л59	57—60		0.5 Pb	0.3 Fe	0.01 Sb	0.003		0.20 Sn	0.9
			(6) Многокомпонентные (специальные) латуни						
			(7) Алюминиевые						
ЛА 85-0.5	84—86	0.4—0.7 Al	0.03 Pb	0.05 Fe	0,005 Sb	0.002	—		0.30
ЛА 77-2	76—79	1.75—2.50 Al	0.07 Pb	0.10 Fe			0.01		
ЛАЖ 60-1-1	58—61	0.75—1.50 Al	—	0.75— 1.50 Fe	0.1—0.6 Mn				
ЛАН 59-3-2	57—60	2.50—3.50 Al	2.0—3.0 Ni	—	—	—	—	—	—
ЛЖМц 59-1-1	57—60	0.1—0.2 Al	0.5—0.8 Mn; 0.2 Pb	0.3—0.7 Sn	0.01 Sb	0.003	0.01		0.25

Сплав	Основные элементы в % *		Примеси в % не более						
	Cu	Al, Si, Sn, Pb, Mn	Pb, Ni, Mn	Fe, Sn	Sb, Mn	Bi	P	Sn, As	Всего примесей
(8) *Кремнистые*									
ЛК 80-3	79—81	2,5—4,0 Si	0,1 Pb	0,6 Fe	0,05 Sb	0,003	0,02	0,2 Sn	1,5
ЛКС 65-1,5-3	63,5—66,5	1—2 Si 2,5—3,5 Pb	0,1 Ni	0,15 Fe	0,005 Sb	0,002	0,01		0,5
(9) *Марганцовые*									
ЛМц 58-2	57—60	1,0—2,0 Mn	0,1 Pb	1,0 Fe	0,005 Sb	0,002	0,01	—	1,2
ЛМцА 57-3-1	55—58,5	2,5—3,5 Al	0,2 Pb					0,5—1,5 Al	1,3
(10) *Никелевые*									
ЛН 65-5	64—67	5—6,5 Ni	0,03 Pb	0,15 Fe	0,005 Sb	0,002	0,01	—	0,3
(11) *Оловянные*									
ЛО 90-1	88—91	0,25—0,75 Sn	0,03 Pb	0,10 Fe	0,005 Sb	0,002	0,01	—	0,2
ЛО 70-1	69—71	1—1,5 Al	0,07 Pb						0,3
ЛО 62-1	61—63	0,7 Al	0,10 Pb						
ЛО 60-1	59—61	1—1,5 Al	0,3 Pb						1,0
(12) *Свинцовые*									
ЛС 74-3	72—75	2,4—3,0 Pb	—	0,10 Fe	0,005 Sb	0,002	0,01	—	0,25
ЛС 64-2	63—66	1,5—2,0 Al							0,30
ЛС 63-3	62—65	2,4—3,0 Al							0,25
ЛС 60-1	59—61	0,6—1,0 Al		0,15 Fe					0,50
ЛС 59-1	57—60	0,8—1,9 Al		0,5 Fe	0,010 Sb	0,003	0,02		0,75

* Остальное цинк.

Key: (1). Alloy. (2). Basic elements/cells in % [1].

FOOTNOTE [1]. Rest is zinc. ENDFOOTNOTE.

(3). Admixtures/impurities in % not more. (4). In all admixtures/impurities. (5). Simple (dual) brasses. (6). Multicomponent (special) brasses. (7). Aluminum. (8). Silicide. (9). Manganese. (10). Nickel. (11). Tin. (12). Lead.

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29. Chemical composition of bronze in %.

(1) Сплав	(2) Основные компоненты[1]				(3) Примеси											(4) Сумма примесей не более
	Al, Be, Si, Cr	Fe	Mn	Ni	As, Al	Sb	Sn	Si	Ni	Pb	P	Fe	Zn	Mn	Al	
(5) Алюминиевые																
Бр. А5	4—6 Al	—								0.03		0.5	0.5			
Бр. А7	6—8 Al		—								0.01			0.5		1.6
Бр. АЖ 9-4	8—10 Al			—					0.5	0.02			1.0			1.7
Бр. АЖМц 10-3-1.5	9—11 Al	2—4	1—2		0.01	0.002	0.1	0.1		0.03	0.1	—	0.5	—	—	0.75
Бр. АЖН 10-4-4	9.5—11 Al	3.5—5.5	—	3.5—5.5					—	0.02			0.2	0.3		0.80
Бр. АМц 9-2	8—10 Al	—	1.5—2.5	—	0.001				0.5	0.03	0.01	0.5	1.0	—		1.70
(6) Бериллиевые																
Бр. Б2	1.9—2.2 Be	—	—	0.2—0.5	0.15 Al	—	—	0.15	—	0.005	—	0.15	—	—	—	0.5
Бр. Б2.5	2.3—2.6 Be															
(7) Кремнистые																
Бр. КМц3-1	2.75—3.5 Si		1.0—1.5	—	0.002	0.002	0.25		0.2	0.03	0.05	0.3	0.5		—	1.1
Бр. Н1-3	0.6—1.1 Si	—	0.1—0.4	2.4—3.4	—	—	0.1	—	—	0.05	0.01	0.1	0.1	—	0.02	0.4
Бр. КН05-2	0.3—0.6 Si		—	1.2—2.3			—			—	—	—	—		—	0.5
(8) Марганцовые																
Бр. Мц5	—	—	4.5—5.5	—	0.01	0.002	0.1	0.1	0.5	0.03	0.01	0.35	0.4	—	—	0.9
(9) Хромовые																
Бр. Х0.5	0.4—1.0 Cr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Key: (1). Alloy. (2). Basic components[1].

FOOTNOTE [1]. Rest is copper. ENDFOOTNOTE.

(3). Admixtures/impurities. (4). Sum of admixtures/impurities is not more. (5). Aluminum. (6). Beryllium. (7). Silicide. (8). Manganese. (9). Chromium.

30. Physical properties of brass.

(1) Сплав	(2) Плотность в Г/см³	(3) Теплопроводность ккал/(м·ч·град)	(4) Коэффициент линейного расширения α · 10⁻⁶ в 1/° С при температуре испытания в °С		(5) Теплоемкость С в кал/г · °С	(6) Удельное электросопротивление ρ в ом·мм²/м	(7) Температурный коэффициент электросопротивления
			20—300	20			
(8) **Простые (двойные)**							
Л96	8,85	0,585	18	17	0,093	0,043	0,0027
Л90	8,73	0.0005	18,2		0,09	0,040	0,00186
Л85	8,75	0,36	18,7	—	—	0,047	0,0016
Л80	8,66	0,34	—	18,8	0,093	0,054	0,0015
Л75	8,63	—	19,6	—	—	—	—
Л68	8,60	0,26—0,28	19		0,093	0,071	0,0015
Л66	8,47	0,286	20,1		0,09	0,069	—
Л62	8,43	0,26	20,6		0,0925	0,072	0,0017
Л59	8,40	0,18	—	21	0,012	0,067	0,0025
(9) **Многокомпонентные (специальные)**							
(10) *Алюминиевые*							
ЛА85-0,5	8,60	0,26	—	18,6	—	—	—
ЛА77-2		0,27	18,3	18,3		0,075	
ЛАЖ60-1-1	8,20	—		21,6		0,090	
ЛАН59-3-2	8,40	0,20	—	19		0,0785	
ЛЖМц59-1-1	8,50	0,241		22		0,093	
(11) *Кремнистые*							
ЛК80-3	8,60	0,1	17	—	—	0,2	—
ЛКС65-1,5-3	8,50		17,2			0,25	
(12) *Марганцовые*							
ЛМц58-2	8,50	0,108	—	21,2	—	0,118	—
ЛМцА57-3-1	8,54	0,172		21,4		0,119	
(13) *Никелевые*							
ЛН65-5	8,65	0,14	—	18,2	—	0,166	—
(14) *Оловянные*							
ЛО90-1	8,8	0,30	18,4	—	—	0,054	—
ЛО70-1	8,58	0,218	19,7			0,0722	
ЛО62-1	8,54	0,26	—			0,0721	
ЛО60-1	8,45	0,24	21,4			0,070	
(15) *Свинцовые*							
ЛС74-3	8,7	0,29	19,8	17,5	—	0,078	—
ЛС64-2	8,5	0,28	—	20,3		0,066	
ЛС63-3				20,5		0,066	
ЛС60-1		0,25	20,8	—		0,064	
ЛС59-1			—	20,6		0,065	0,0026

Key: (1). Alloy. (2). Density in g/cm^3. (3). Thermal conductivity kcal/(m·h·deg). (4). Coefficient of linear expansion $\alpha \cdot 10^{-3}$ in 1/°C at temperature of testing in °C. (5). Heat capacity C in cal/g·°C. (6). Specific resistance ρ in $\Omega \cdot mm^3/m$. (7). Temperature coefficient of electrical resistance. (8). Simple (dual). (9). Multicomponent (special). (10). Aluminum. (11). Silicide. (12). Manganese. (13). Nickel. (14). Tin. (15). Lead.

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31. Physical properties of bronze.

(1) Сплав	(2) Плотность в Г/см³	(3) Теплопроводность в кал/см·сек·°С	(4) Коэффициент линейного расширения α·10⁻⁶ при °С: 25—300	20	(5) Теплоемкость в кал/г·°С	(6) Удельное электросопротивление в ом·мм²/м	(7) Температурный коэффициент электросопротивления
			(8) Алюминиевые				
Бр. А5	8,2	0,25	—	18,2		0,0995	0,0008
Бр. А7	7,8	0,19	17,8	—		—	
Бр. АЖ 9-4	7,5	0,14	16,2		—	0,120	
Бр. АЖМц10-3-1,5			—	10		0,169	—
Бр. АЖН 10-4-4	7,0	0,18		17,1		0,193	
Бр. АМц 9-2		0,17	17	—		0,11	
			(9) Бериллиевые				
Бр. Б2; Бр. Б2,5	8,23	0,25	16,6	—	0,10	0,10	—
			(10) Кремнистые				
Бр. КМц 3-1	8,40	0,08—0,11	—	15,8	—	0,15	—
Бр. КН 1-3 и Бр. КН 0,5-2	8,8	—		18		0,046	
			(11) Марганцевые				
Бр. Мц 5	8,6	0,20	20,4	—	—	0,197	—
			(12) Хромовые				
Бр. Х 0,5	8,9	—	—	—	—	0,03	0,0025

Key: (1). Alloy. (2). Density in g/cm³. (3). Thermal conductivity in cal/cm·s·°C. (4). Coefficient of linear expansion α·10⁻⁶ at °C. (5). Heat capacity in cal/g·°C. (6). Specific resistance in Ω·mm²/m. (7). Temperature coefficient of electrical resistance. (8). Aluminum. (9). Beryllium. (10). Silicide. (11). Manganese. (12). Chromium.

32. Classification of copper on hardness.

(1) Состояние	(2) Свойства	(3) Показатели свойств	(1) Состояние	(2) Свойства	(3) Показатели свойств
(4) Мягкая	σ_s (7) в кГ/мм²	7	(5) Литая	(8) $a_н$ в кГм/см²	12
(6) Твердая	$\sigma_в$ (7) в кГ/мм²	38	(4) Мягкая	HB (7) в кГ/мм²	35—40
»		20—24 40—50			
»	δ в %	50 6	(6) Твердая	σ_{-1} (7) в кГ/мм²	90—120 6,7
»	ψ в %	75 35	»	(9) на базе 10⁶ циклов	11

Key: (1). State. (2). Properties. (3). Indices of properties. (4). Soft. (5). Cast. (6). Solid. (7). in kg/mm². (8). in kgfm/cm². (9). On base of 10^3 cycles.

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33. Classification of brass.

(1) Сплав	$\sigma_в$	$\sigma_{0,2}$	E	δ	ε	HB	(4) Классификация по твердости
	(2) в $кГ/мм^2$			(3) в %			
			(5) Простая (двойная)				(6)
Л96	40	39	11 400	2	—	—	Твердая (наклеп 50%)
Л90	60	30	9 150	4	60	130	Твердая (7)
Л85	52,5	50,4	10 600		—	120—130	»
Л80	56	36	15 350	10	40	145	»
Л75	59—68	51—57	10 500	5—7	—	—	(8) »
Л70	52		—	21	58		Холоднотянутая
Л68	52	—	11 500	12	52	150	Твердая (7)
Л66	70		10 500	4	—	—	(6) Твердая (наклеп 60%)
Л62	68	48	10 000	3—4		140	»
Л59	50	20	10 600	10	40	103	Твердая (7)
			(9) Многокомпонентная специальная				
			(10) Алюминиевая				(11)
ЛА85-0.5	30—40		—	60	50	54	Мягкая
ЛА77-2	58			10	—	50	(6) Твердая (наклеп 50%)
ЛАЖ60-1-1	76	—	10 500	9	30	170	(7) »
ЛАН59-3-2	70		10 000	10	20	182	Твердая
ЛЖМц59-1-1	60		10 600	—	15	160	»
			(12) Кремнистая				(13)
ЛК80-3	30—50	10,5	9 800	15—40	—	90—110	В литом состоянии
ЛКС65-1,5-3	70	16	9 800	8		100	(14) Деформированная
			(15) Марганцовая				(7)
ЛМц58-2	60	—	10 000	10	—	120	Твердая
ЛМцА57-3-1	—		—	—		—	
			(16) Никелевая				(6)
ЛН65-5	60	—	11 200	1,5	—	—	Твердая (наклеп 60%)
			(17) Оловянная				(11)
ЛО90-1	28	9	10 500	40	55	55	Мягкая
ЛО70-1	58	—	10 600	10	28	142	(7) »
ЛО62-1	44	38	10 500	25	—	140	Твердая
ЛО60-1	56	42		10		—	»
			(18) Свинцовая				(7)
ЛС74-3	60—70	52—61		2—5		—	Твердая
ЛС64-2	58—67	45—50	10 500	4—6	—	100—120	»
ЛС63-3	58	45		5		—	»
ЛС60-1	65	56					»

Key: (1). Alloy. (2). in kg/mm². (3). in %. (4). Classification on hardness. (5). Simple (dual). (6). Solid (work hardening/peening 50%). (7). Solid. (8). Cold-drawn. (9). Multicomponent special. (10). Aluminum. (11). Soft. (12). Silicide. (13). In cast state. (14). Deformed. (15). Manganese. (16). Nickel. (17). Tin. (18). Lead.

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34. Mechanical properties of bronze.

(1) Сплав	$\sigma_в$	$\sigma_{0,2}$	E	δ	ψ	HB	(4) Примечание
	(2) в $кГ/мм^2$			(3) в %			
			(5) Алюминиевая				
Бр. А5	80	50	11 000	4	—	200	
Бр. А7	100	—	11 500	3—10	40	154	
Бр. АЖ 9-4	55	35	11 600	5	—	160—200	
Бр. АЖМц 10-3-1,5	60	19	10 000	20		120—140	(6) Твердая
Бр. АЖН 10-4-4	77	—	13 000	9	11	225	
Бр. АМц 9-2	60	50	9 200	25	—	160	
			(7) Бериллиевая				
Бр. Б2	95	85—90	11 700	1—2	—	350—400	(8) Твердая, облагороженная
			(9) Кремнистая				
Бр. КМц 3-1	90	65	12 000	0,5	—	—	(10) Наклеп 60%
Бр. КН 1-3 и Бр. КН 0,5-2	60	52	—	12	28	150—200	—
			(11) Марганцовая				
Бр. Мц 5	60	50	10 500	2	—	160	(6) Твердая
			(12) Хромовая				
Бр. Х 0,5	50	40	138 000	11	40	130—150	—

Key: (1). Alloy. (2). in kg/mm^2. (3). in %. (4). Note. (5). Alumi[illegible]. (6). Solid. (7). Beryllium. (8). Solid, refined. (9). Silicide. (10). Work hardening/peening 50%. (11). Manganese. (12). Chromium.

35. Effect of oxygen on the properties of copper.

(1) Содержание кислорода в %	(2) $\sigma_в$ в кГ/мм²	δ	ψ	(4) σ_{-1} в кГ/мм²
		(3) в %		
(5) *Медь, деформированная и отожженная при 700° С, 30 мин*				
0.016	22,7	54	77	7,7
0.040	22,4	50	72	9,4
0.060	22,7	58	70	9,1
0.090	23,1	53	85	8,4
0.170	24,1	49	57	7,7
0,380	25,9	55	39	
(6) *Медь холоднотянутая*				
0.030	26,2	30	73	12,0
0.049		29	68	12,2
0.094	26,0	27	63	13,3
0.220	26,7		40	11,9

Key: (1). Oxygen content in %. (2). in kg/mm². (3). in %. (4). σ_{-1} in kg/mm². (5). Copper, deformed and annealed at 700°C, 30 min. (6). Copper cold-drawn.

36. Effect of phosphorus on properties of copper.

(1) Содержание фосфора в %	(2) $\sigma_в$ в кГ/мм²	δ	ψ	(4) σ_{-1} в кГ/мм²
		(3) в %		
0,016	24,1	62	73	7,7
0,030	22,4	59	82	8,4
0,045	22,7	50	86	8,7
0,096	23,1	62	80	9,9
0,148	23,8	63	85	10,5
0,178	24,5	61	85	9,2
0,254	24,8	63	84	9,4
0,494	26,9	62	90	10,8
0,600	26,9	63	84	11,6
0,700	28,0	64	81	12,2
0,950	28,0	66	85	11,9

Key: (1). Content of phosphorus in %. (2). in kg/mm². (3). in %. (4). α^{-1} in kg/mm².

37. Effect of antimony on the properties of copper.

(1) Содержание сурьмы в %	(2) $\sigma_в$ в кГ/мм²	δ (3) в %	ψ	(4) σ_{-1} в кГ/мм²	(1) Содержание сурьмы в %	(2) $\sigma_в$ в кГ/мм²	δ (3) в %	ψ	(4) σ_{-1} в кГ/мм²
0.004	22.2	62	74	5.4	0.002	23.4	68	78	5.9
0.020	22.6	61	74	5.9	0.22	23.6	—	—	7.0
0.050	22.5	66	72	5.8	0.47	23.4	66	66	7.8

Key: (1). Content of antimony in %. (2). in kg/mm². (3). in %. (4). σ^{-1} in kg/mm².

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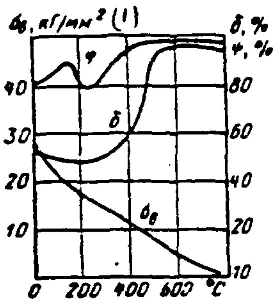

Fig. 82.

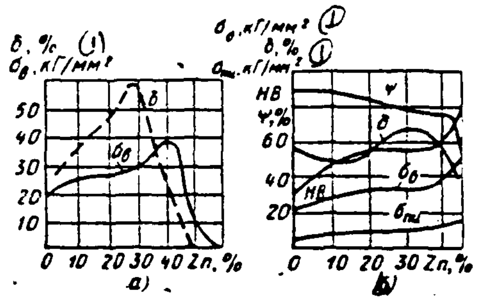

Fig. 83.

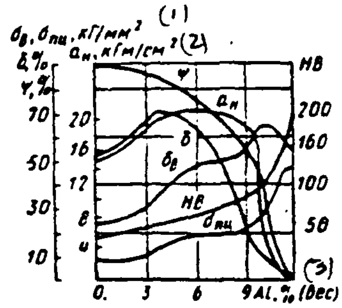

Fig. 84.

Fig. 82. Change in mechanical properties of non/without-oxygen copper at high temperatures.

Key: (1). kg/mm².

Fig. 83. Dependence of mechanical properties of brasses on content of zinc.

Key: (1). kg/mm².

Fig. 84. Change of mechanical properties of aluminum bronze in dependence on content of aluminum.

Key: (1). kg/mm². (2). kgfm/cm². (3). (weight).

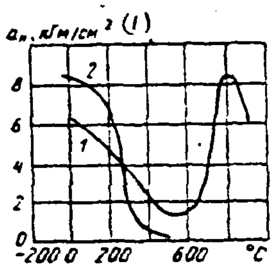

Fig. 85.

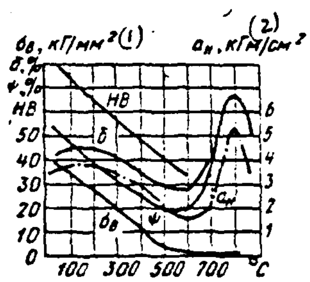

Fig. 86.

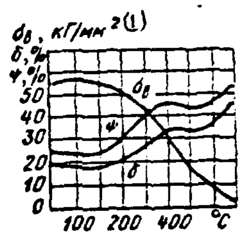

Fig. 87.

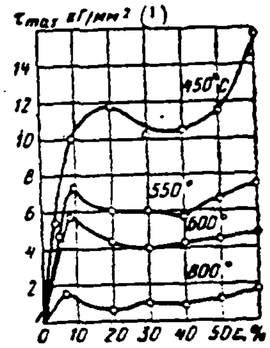

Fig. 88

Fig. 85. Change in impact toughness of brass (20% Cu) in dependence on content of lead (1 - without lead; 2 - containing 0.5% Pb).

Key: (1). kgfm/cm².

Fig. 86. Diagram of plasticity of brass Л96.

Key: (1). kg/mm². (2). kgfm/cm².

Fig. 87. Diagram of plasticity of brass Л90.

Key: (1). kg/mm².

Fig. 88. Diagram of plasticity of brass Л80.

Key: (1). kg/mm².

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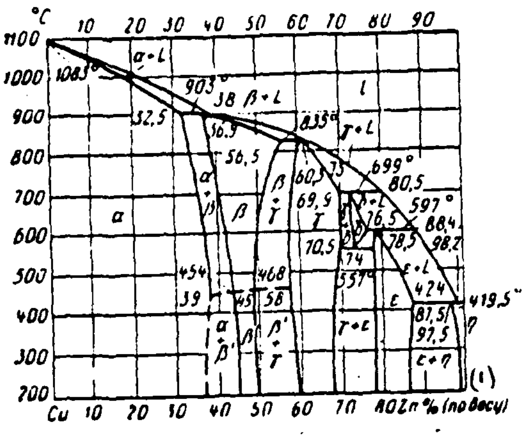

Fig. 89.

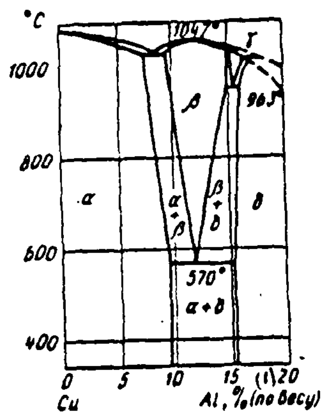

Fig. 90.

Fig. 89. Constitution diagram Cu-Zn.

Key: (1). (by the weight).

Fig. 90. Constitution diagram Cu-Al.

Key: (1). (by the weight).

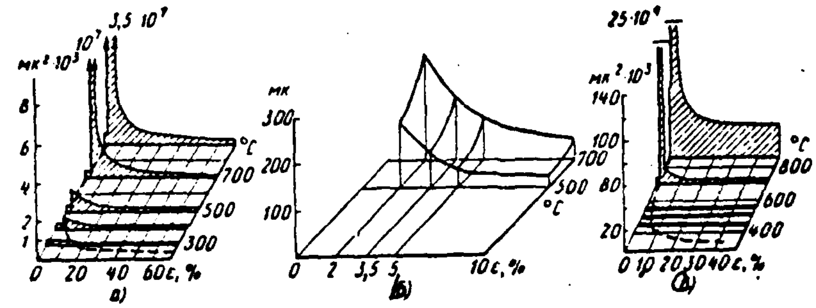

Fig. 91. Diagrams of the recrystallization of the treatment: a) the electrolytic copper: b) brass of the type Л62; c) brass of the type Л68.

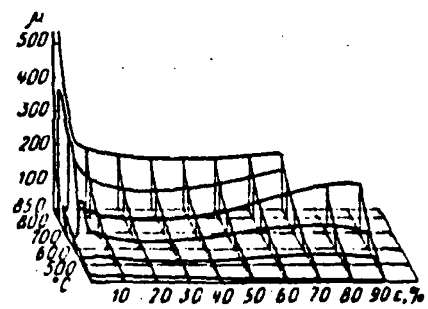

Fig. 92. Diagram of recrystallization of working brass Л70.

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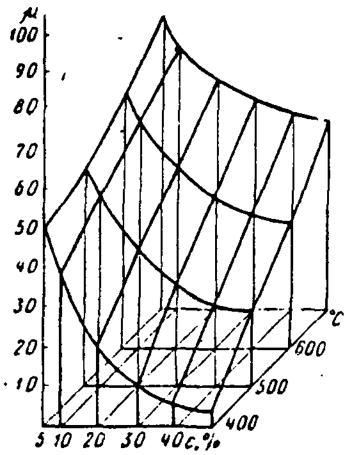

Fig. 93.

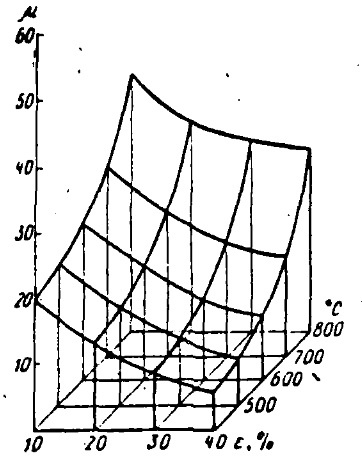

Fig. 94.

Fig. 93. Diagram of recrystallization of working brass ЛО70-1.

Fig. 94. diagram of recrystallization of working brass Л59.

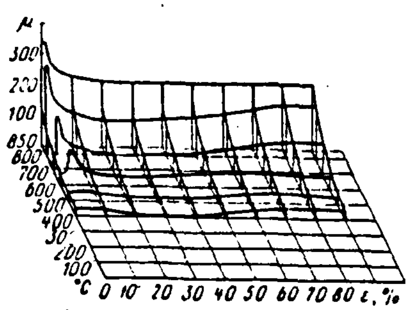

Fig. 95. Diagram of recrystallization of working brass Л85.

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Chapter 2.

METHODS AND THERMOMECHANICAL PARAMETERS OF FORGING AND STAMPING.

Methods of forging and stamping.

The preliminarily wrought by extrusion/pressing alloys of nonferrous metals possess a sufficient reserve of plasticity and them it is possible to work by pressure even in the stressed states with the presence of the stretching strains and stresses/voltages. However, the ingots of the majority of alloys and the preliminarily wrought high-strength alloys should be worked, as far as possible, in the softer stressed states by extrusion/pressing in the containers and by open-die forging with the limited broadening, and also in closed dies.

High alloys possess the lowered/reduced plasticity in the presence in volume of tensile stresses being deformed and the absence

of the forces, which prevent destruction. Therefore such alloys in the form of the pressed rods must be worked in the open dies with the limited broadening, and also in the closed dies with the vertical surfaces of impressions, which do not have slope angles, for example, in the horizontal forging machines or under the hammer or the press in the closed dies with the knockout.

Low-plasticity and brittle alloys should be worked extrusion/pressing with the counterpressure, when plastic deformation is accomplished/realized during the nonuniform cubic compression with high main compressive stresses and during the low strains and with the tensile stresses.

The classification of the methods of forging and stamping depending on the plasticity of alloys is given in Tables 1 and 2.

1. Groups of the methods of working by pressure.

(1a) Группа	(2a) Методы обработки
1. Методы, которые могут приводить к хрупкому состоянию	2 Свободная ковка на плоских бойках 3 Свободная ковка в плоских ручьях многоручьевых штампов 4 Прокатка на гладких валках 5 Волочение
6 Методы, повышающие пластичность	7 Ковка в фигурных бойках 8 Ковка в пластичной оболочке 9 Ковка в фигурных ручьях многоручьевых штампов 10 Штамповка в открытых штампах со свободным уширением 11 Прокатка в калибрах
12 Методы, значительно повышающие пластичность	13 Прессование выдавливанием 14 Штамповка в открытых штампах с ограниченным уширением 15 Штамповка в закрытых штампах с ограниченным уширением 16 Штамповка в закрытых штампах без уширения 17 Прессование выдавливанием с противодавлением 18 Штамповка в закрытых штампах с противодавлением 19 Штамповка в пластичной оболочке

Key: (1a). Group. (2a). Methods of working. (1). Methods, which can lead to brittle state. (2). Smith forging on platens. (3). Smith forging in flat/plane grooves of multipass dies. (4). Rolling on smooth rolls. (5). Drawing. (6). Methods, which raise plasticity. (7). Forging in form-shaping dies. (8). Forging in plastic shell. (9). Forging in figure impressions of multipass dies. (10). Open-die

forging with free broadening. (11). Rolling in bores. (12). Methods, which significantly raise plasticity. (13). Extrusion/pressing by extrusion. (14). Open-die forging with limited broadening. (15). Flashless die forging with limited broadening. (16). Flashless die forging without broadening. (17). Extrusion/pressing by extrusion with counterpressure. (18). Flashless die forging with counterpressure. (19). Stamping in plastic shell.

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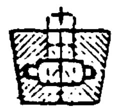
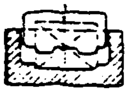
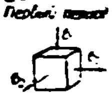
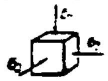
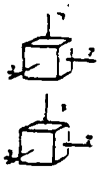
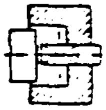
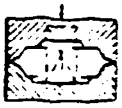
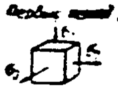
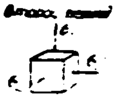
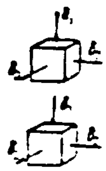
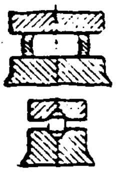
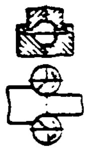
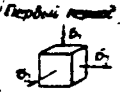
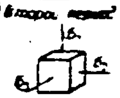
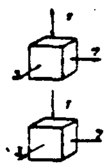
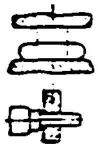
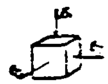
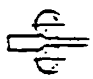
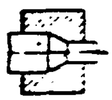
2. Classification of methods of working by pressure due to stress-strain and plastic states of machined metal (Korneyev N. I.).

(1) Группа	(2) Методы обработки давлением	(3) Схемы методов обработки давлением	(4) Величина главных напряжений. Вид напряженного состояния		(6) Величина главных деформаций. Вид деформированного состояния			(7) Величина пластичности и сопротивления деформированию. Допустимая степень деформации за каждое обжатие в %
			σ_1	(5) σ_2 и σ_3	δ_1	δ_2	δ_3	
I	(8) Прессование выдавливанием и штамповка под прессом в закрытых штампах без уширения с противодавлением		(9) Очень большие		(10) Большие			(11) Очень высокие. 75 и выше
П	(12) 1. Прессование выдавливанием без противодавления в контейнерах							
	(13) 2 Штамповка в закрытых штампах без уширения и противодавления							

III	(14) 1. Штамповка в закрытых штампах с ограниченным уширением на молотах и прессах (безоблойная штамповка)		(10) Большие (18) Первый период  (19) Второй период 	(10) Большие	(15) Большие и средние	—	(16) Высокие. До 75
							
	(17) 2. Штамповка на горизонтально-ковочных машинах в закрытых штампах						
	(20) 3. Штамповка в открытых штампах с ограниченным уширением на молотах и прессах						
IV	(21) Штамповка в открытых штампах с неограниченным уширением на молотах и прессах		(22) Средние (18) Первый период  (19) Второй период 	(22) Средние	(10) Большие		(23) Средние. 50—80
							

1 Группа	2 Методы обработки давлением	3 Схемы методов обработки давлением	4 Величина главных напряжений Вид напряженного состояния		6 Величина главных деформаций Вид деформированного состояния			7 Величина пластичности и сопротивления деформированию. Допустимая степень деформации за каждое обжатие в %
			σ_1	5 σ_2 и σ_3	δ_1	δ_2	δ_3	
V	24 1. Ковка с боковым давлением (осадка в оболочке и вытяжка в фигурных бойках)		23 Средние		22 Среднее	25 Малое	10 Большие	23 Средние 40—50
	26 2. Прокатка сорта в закрытых ручьях		15 Первый вариант  19 Второй вариант 					
	27 3. Прокатка сорта в открытых ручьях с ограниченным уширением							

VI	(28) 1. Свободная ковка без бокового давления (осадка и вытяжка) на плоских бойках		(30) Малые 	(27) Средние — (10) Большие 	(31) Малые. 40—50 (30 для малопластичных сталей и сплавов)
	(29) 2. Прокатка сорта в открытых ручьях с неограниченным уширением				
	(32) 3. Прокатка на гладких валках				
VII	(10) Волочение		(30) Малые 	(25) Малое — (25) Среднее — (10) Большое 	(30) Малые 30

Key: (1). Group. (2). Methods of working by pressure. (3). Diagrams of methods of working by pressure. (4). Value of principal stresses. Form of the stressed state. (5). and. (6). Amount of main strains. Form of the strained state. (7). Value of plasticity and resistance to deformation. Permissible degree of strain for each reduction in %. (8). Extrusion/pressing by extrusion and stamping under press in closed dies without broadening with counterpressure. (9). Very large. (10). Large. (11). Very high. 75 are above. (12). Extrusion/pressing by extrusion without counterpressure in containers. (13). Flashless die forging without broadening and counterpressure. (14). Flashless die forging with limited broadening on hammers and presses (flash ss die forging). (15). Large and average/mean. (16). High. to 75. (17). Stamping in horizontal forging machines in closed dies. (18). First period. (19). Second period. (20). Stamping in open dies with limited broadening on hammers and presses. (21). Stamping in open dies with unlimited broadening on hammers and presses. (22). Average/mean. (23). Average/mean. 50-60. (24). Forging with lateral pressure (upsetting in shell and drawing in figure faces). (25). Low. (26). Rolling of type in box grooves. (27). Rolling type in open grooves with limited broadening. (28). Smith forging without lateral pressure (upsetting and drawing) on platens. (29). Rolling type in open grooves with unlimited broadening. (30). Low. (31). Low. 40-50 (30

for low-ductility steel and alloys). (32). Rolling on smooth rolls.

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In the methods of the working by pressure, in which the strain is composed of the free flow of metal with the free broadening and the metal flow under the effect of lateral pressure, plastic deformation must be divided into two periods: 1) plastic deformation flows/occurs/lasts with the free broadening; 2) acts lateral pressure and occurs a considerable increase in the value of main compressive stresses.

In the first period the degree of deformation can be applied only in the limits, the permissible deformations for this metal or alloy. For brittle metal it composes 10-25%; for low-plasticity 30-50%, while for the metals and the alloys, which possess the average/mean and high reserve of plasticity, it can be >60%.

Upon transfer from the methods of working by pressure, which call the brittle state of the metal being deformed, to the methods, which raise plasticity and considerably raising the plasticity, as a result of an increase in main compressive stresses, increases the resistance to deformation.

To each method correspond the specific stress-strain state, the value of main compressive stresses, the plastic state of the metal being deformed, structure and mechanical properties.

The classification of the methods of working metals and alloys proposed consists of the groups, each of which is characterized by the form of the stress-strain state; with the value of principal stresses; by the resistance to deformation; by the form of the strained state; with the amount of main deformations; by the plasticity of the metal being deformed, determined by the permissible deformation.

In proportion to the accumulation of quantitative data the classification will be supplemented by new groups, new quantitative indices, which will make it possible even to more accurately produce the evaluation of the stressed and plastic states of the metal being deformed and the scientific substantiation of the methods of working by pressure depending on the reserve of the plasticity of metals and alloys.

Group I. The plastic deformation of metal occurs under the conditions for hydrostatic compression, with which from the very beginning of working by pressure the metal undergoes the effect of cubic compression with high main compressive stresses, and the

stretching deformations and stresses/voltages are extremely low. In this case with an increase in the counterpressure the portion of the stretching deformations and stresses/voltages sharply is decreased, and the technological plasticity of the metal being deformed grows/rises. The stressed state corresponds to nonuniform cubic compression, and the strained state to opposite diagram with two compressive strains and one - elongation.

With the extrusion/pressing with the counterpressure and flashless die forging without the broadening with the counterpressure brittle and wrought alloys are deformed without the signs/criteria of brittle state and crack formation. The value of counterpressure must be for each alloy strictly defined. With the insufficient value of counterpressure the brittleness of metal or alloy can be and not be removed. The value of counterpressure can be determined from the relationship/ratio

$$p = 0{,}1P,$$

where P - pressure of press.

They set experimentally for each metal and alloy of the value of counterpressure.

Principal stresses, resistance to deformation and plasticity are

raised with an increase in the counterpressure. Consequently, an increase in the plasticity at the considered/examined methods of working by pressure is achieved due to an increase in the resistance to deformation and expenditure of great work for working by pressure.

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Group II is characterized by the mechanical diagram of the deformation, which corresponds to nonuniform cubic compression, and by the presence of lateral pressure from the very beginning of deformation. This mechanical mode/conditions of deformation during the extrusion/pressing by extrusion and during the stamping is observed for the duration entire period of working. Exception is use/application in the beginning of the extrusion/pressing the so-called pre-pressing - the operation, with which the metal in the container undergoes common free settling for increasing the degree of the deformation of the center of the section/cut of blank. Introduction to this operation removes a shortcoming in the extrusion/pressing by the extrusion, with which the middle part of the section/cut is deformed as the periphery of section/cut, only during the high deformations. The degree of deformation with the pre-pressing on the average does not exceed 25%, that the brittle state of malleable alloys is not caused.

During working of metals and alloys by the methods of this group main compressive stresses, which affect in the metal being deformed, sufficiently high, and tensile stresses are relatively small. The form of the stressed state corresponds to nonuniform cubic compression, and the deformed state is characterized by the opposite diagram, in which two compressive strains, which affect from the deforming force and the lateral pressure from the side of the walls of container and one tensile strain, which appears during metal flow from the eyelet of matrix/die. The latter leads in many instances of extrusion/pressing with extrusion to a decrease in the plasticity of the pressed metal, and under specific conditions for working (with an increase in the velocity and a decrease in the temperature of extrusion/pressing) - to crack formation in the pressed rods, profiles/airfoils, ducts/tubes/pipes and stampings. Thus, the stress-strain state of metal during the extrusion/pressing by extrusion from the observance of the established/installed thermomechanical mode/conditions obtains satisfaction the plastic deformation of metals and alloys with this method, that takes place with the favorable loading.

Therefore the methods of working the second group find wide application for the cold and hot working by the pressure of relatively wrought alloys (aluminum, magnesium, titanium, etc.). During the working by pressure by these methods the plasticity of the

machined metals and alloys proves to be sufficiently high. The process of working is accomplished/realized in one machine for one-two operations, without the formation of projecting edges and during the considerable deformations. The latter excludes the possibility of working by pressure during ultimate strain and provides obtaining in the deformed metal of the macrostructure correctly oriented in the direction of the metal flow and high mechanical properties. As a result of the drag-rise characteristics to deformation during this stressed state and use/application of high deformations in many instances it is expedient to apply for the working by pressure by such methods forge-press, crank and hydraulic presses, and also horizontal forging machines and machines for th pulse methods of processing.

Group III. In the beginning of working, in first period of deformation, before the onset of the contact of metal with the walls of die/stamp and emergence of lateral pressure, the deformation is accomplished/realized during the free broadening and the considerable lateral deformation. This creates dangerous deformations and tensile stresses in the metal.

The subsequent, second period, relates to that moment/torque of the deformation, when appears the lateral pressure from the side of the walls of die/stamp, which continuously increases in proportion to

filling of die/stamp and toward the end of the working reaching maximum value. With the methods of the third group it changes after the emergence of lateral pressure or reaction with the side of the rigid walls of die/stamp, the process of deformation, and the considerable portion of the stretching deformations and stresses/voltages is replaced by compressive.

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Thus, the special feature/peculiarity of this group of the methods of processing is the separation of the process of plastic deformation into two periods: the first period, which is characterized by the extremely rigid stress-strain state, during which the metal being deformed is located under the effect of dangerous stresses/voltages and tensile strains, which in many cases can cause the brittle state of metal; the second period, when the considerable portion of tensile stresses and deformations is replaced by compressive and plasticity of the machined metal sharply it is raised in the stress-strain state.

Therefore the stress-strain state of metal during the working by pressure by the methods of the third group must be described by two different ones for the first and second periods of the working by mechanical and deformation diagrams.

In the first period of working the stressed state in the form of nonuniform cubic compression with compressive stresses low in the value acts, and deformation diagram - opposite, with one compressive strain and two stretching deformations.

In the second period of working in the stressed state, which corresponds to nonuniform cubic compression, compressive stresses considerably increase, and in the deformation opposite diagram only one deformation remains stretching, and two others are tensile strains.

The basic condition, which must be observed during the working by pressure by the methods of the third group, for warning/preventing the sharp incidence/drop in plasticity and decomposition of the metal being deformed, is the limitation of deformation in the first period of working with the free broadening to the emergence of the contact of the metal to be stamped with the walls of die/stamp. During this period it is possible to apply only permissible in the value for this metal deformations. The permissible deformations for the wrought alloys must not exceed 30-50%, for alloys of average/mean plasticity 60%, but for the highly ductile alloys they can reach 70% and more.

Group IV. In the process of stamping considerable deformation flows/occurs/lasts during the first period of working with the free broadening. In the metal being deformed appear the stretching deformations and stresses/voltages in many instances of high value. Therefore method is applied for the working by pressure of metals and alloys of average/mean and high plasticity.

A reduction/descent in deformations and tensile stresses and an increase in the plasticity is produced, as this was indicated during the analysis of the methods of working the third group, also by the limitation of deformation in the first period of working with the free broadening, without exceeding the permissible deformations indicated for the alloys of different plasticity. This can be achieved/reached by stamping annular billets, close ones in the geometric form to the finished article and decreasing the lateral deformation. Especially this must be considered during stamping of the alloys, which possess the relatively low plasticity (aluminum, magnesium and copper alloys).

Second period of deformation in the open dies appears after the emergence of the contact of the machined metal with the walls of die/stamp. This period is characterized by an abrupt change of the mechanical diagram of deformation, in the direction of an increase in main compressive stresses, which leads to an increase in the

plasticity of metal.

The stress-strain states of metal in both periods of deformation will be here analogous to those, which were in detail presented for the methods of working the third group.

Group V. Plastic deformation is accomplished/realized during the limited broadening and the lateral deformation and the considerable stretch deformation. This occurs, because lengthwise grooves with the forging in the faces and the dies/stamps are open.

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Therefore the metal flow free without the lateral pressure occurs lengthwise. Forces of friction, which are usually small, prevent the metal flow lengthwise only.

The described pattern of the flow of metal during the forging in the grooves determines the favorable stress-strain state of metal, which affects during the working by these methods.

As a result of the free flow of metal in the beginning of deformation in the transverse and longitudinal direction the process of working is accomplished/realized with relatively low main

compressive stresses, especially second and third principal stresses, which during this period of deformation are equal to forces of friction.

The diagram of deformations in the first period of working is opposite with two those stretching (longitudinal and transverse) and is one is compressive, from the deforming force.

This stress-strain state of metal into first period of the working by the methods in question causes the considerable incidence/drop in the plasticity of the metal deformed by ductile, which must be considered during the development of the transitions/transfers of forging.

In second period of deformation, when is created the contact of the machined metal and lateral pressure, in the diagram of deformations one tensile strain is replaced by compressive also already two compressive and one that stretches deformations act in the deformation diagram. In this case an increase and second main compressive stresses occurs, which leads to a considerable increase in the plasticity of metal in the second period of forging.

The methods of forging this group find wide application during the manufacture of the annular billets before stamping of alloys even

with the relatively low reserve of plasticity.

For increasing the plasticity of wrought alloys by the methods of working fifth group it is necessary to apply least possible deformations into the first period and the highest in the second period, when lateral deformation is relatively small and when lateral pressure acts.

Since the given methods of processing with respect to the stress-strain state have considerable advantages over the free ductile on the platens, it is necessary the smith forging of ingots and blanks on the platens to replace by the forging in form-shapi dies or grooves of multipass dies, which consist of the grooves for the preliminary forging of blanks and grooves for the stamping.

Group VI. Metal working is accomplished/realized during the nonuniform all-round compression with low compressive principal stresses and considerably by higher than in all preceding/previous methods of working, by tensile stresses and by deformations. First main compressive stress in these methods of working acts from the deforming force, and the second and the third - from force of friction, in the value, usually considerably less in comparison with the force, which accomplishes/realizes deformation. Therefore forging in such stressed states occurs virtually without the lateral

pressure.

Since in this stressed strained condition occurs in unlimited free broadening and absence of lateral pressure from the side of the rigid walls of instrument, and consequently, with low compressive stresses, which prevent decomposition, during the smith forging on the platens, especially wrought alloys, in many instances is created the brittle state of the metal being deformed with crack formation.

To the creation of the brittle state of metal in the process of working contributes also the opposite deformed diagram, which affects with such methods of the working, in which only first main deformation - compressive and two others, the second and the third - stretching (from the considerable lateral deformation in the free broadening and the absence of lateral pressure).

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An increase in the plasticity of alloys during working of ductile on the platens is possible only by a reduction/descent in degree and deformation rate, and also by the use/application of wide faces during the forging for an increase in force of friction and increase in compressive stresses. But working under such conditions for deformation depresses productivity.

The methods of working the sixth group it is expedient to apply

for forging of highly ductile and possessing the average/mean reserve of the plasticity alloys.

If necessary for working wrought alloys forging on the smooth faces should be produced with the limitation of broadening and replaced the ductile in the figure faces and in the plastic shells. It is expedient to apply also the preliminary deformation of ingots by extrusion/pressing, by extrusion without the counterpressure and in the presence its, after which the plasticity of metals and alloys considerably is raised.

Group VII. contains such technological processes of the work. by pressure as drawing, whose stress-strain state is characterized by opposite form. In this stress-strain state one principal stress even one main deformation - stretching. The presence of tensile stresses and deformations with the drawing is made this technological process extremely "rigid".

A change in the stressed and plastic state upon transfer from the first group of the methods of working to the sixth is characterized by falling plasticity, decreasing the permissible deformation, by decrease in the resistance to deformation or deforming force.

Therefore the first two groups and especially the first group of the methods of working by pressure are advantageous from the point of view of high plasticity and almost unlimited permissible deformation of machined metal and are unfavorable in view of the necessary use/application of machines of large power, since the resistance to deformation of the machined metal in such stressed states considerably grows/rises. The great advantage of given methods of processing is also the stability of the processes of deformation with respect to the constancy of the basic thermomechanical parameters of processing pressure (speed, degree and deformation temperature) and uniformity of deformation.

The third and the especially fourth of the group of the methods of working, on the contrary, are advantageous with respect to the possible use/application of machines of a comparatively low power and expenditure of small work for the deformation and are not advantageous because of the possibility decreases in the plasticity of the machined metal and low deformation, which can be allowed during the working. Should be considered also essential shortcomings in these methods, consisting in the difficulty observances of the constancy of the thermomechanical condition of deformation and unavoidable nonuniform deformation.

Therefore the methods of working the first and second groups

should be applied, where it is necessary to raise the plasticity of the machined alloys and the uniformity of properties, manufactured semi-finished products. However, the methods of working the third and fourth groups should be applied for working of alloys with the large reserve of plasticity and when of the semi-finished products being deformed is not required upper limit of mechanical properties.

It follows from the classification that working wrought alloys by ductile and hot stamping must be performed in the figure faces and the die impressions, instead of the platens used and the grooves with as the small as possible free broadening of metal both during the smith forging and during the stamping; by instrument with least possible angles of the slope of working surfaces; in the closed dies instead of the open dies used.

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Aluminum alloys. Technical aluminum (АЛ1 and AL) has high plasticity. It can be deformed by cold and hot ductile and stamping with the different types of loading. In this case a change in the deformation rate does not cause a considerable decrease in the plasticity of aluminum. Technical aluminum is subjected to forging and stamping on the presses, the forging machines and the hammers predominantly on the platens and in the open dies.

Aluminum alloys soft (AV, AMts, AMr1, AMr2, АД31, АД33, etc.) and average/mean strength (Д1, AK2, AK4, AK6, ВД17, AMr6, etc.) have a good plasticity. They are worked by ductile and hot stamping in the stress-strain states, in which act the deformations and tensile stresses. Forging the alloys of these groups is produced on the hammers and the hydraulic presses on the platens and in the open and semienclosed dies. The hot die forging of the soft and average/mean strength of alloys is made in the hammers, the forging machines, on the crank and hydraulic presses.

Fine/small and middle machine parts stamp on the crank presses, and large/coarse - on the hydraulic presses. Large/coarse stampings can be stamped, also, on the hammers. Aluminum alloys highly ductile and average/mean plasticity can be worked by pressure with that stress-strained states from the rigid (upsetting with the free broadening) to the soft (flashless die forging without the broadening) mechanical diagrams of deformation.

The aluminum alloys of high strength (B93, B95, B96, AK3, BAД23, etc.) have the lowered/reduced plasticity in comparison with the alloys of other groups.

These alloys are worked by ductile and hot stamping in the softer stress-strain states and predominantly on the hydraulic and crank presses. Working alloys with this deformation rate with the observance of the established/installed parameters of forging and hot die forging does not shift them into the brittle state.

Stamping fine/small and average sizes of parts is produced on the crank presses, large/coarse - on the hydraulic presses. The alloys of high strength can be worked by ductile and hot stamping, also, on the hammers.

For working of wrought alloys it is necessary to apply the closed and semienclosed methods of deformation.

Brittle aluminum alloys, for example, of the type of system Be-Al and "SAP" must be worked by the new methods of extrusion/pressing and stamping with the counterpressure and with the use/application of plastic shells.

The deformation of the ingots of all aluminum alloys, as a rule, for the exception/elimination of the action of considerable tensile stresses and deformations must be produced by extrusion/pressing for deformation 50-60%.

The determination of the methods of forging and stamping and form of the stress-strain state depending on the plasticity of aluminum and other alloys must be produced according to the classification of the methods of working by pressure due to the stressed and plastic states of the machined alloy.

Magnesium alloys. The alloys of system magnesium - manganese with the small additions of cerium (MA1, MA8) possess high plasticity during hot and fabrication and undergo deformation in the soft and rigid stressed states (forging, stamping, etc.).

The alloys of magnesium with different content of aluminum and additives of small quantities zinc and manganese (MA2, MA2-1, MA3, MA5) have higher strength characteristics and lowered/reduced reserve of plasticity. The plasticity of these alloys substantially is depressed with an increase in the content in them of aluminum.

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The alloy MA2, which satisfactorily undergoes forging and hot die forging even in the rigid mechanical diagrams of deformation, possesses the greatest plasticity in the hot state. However, the deformation rate in this case must not be high.
Approximately/exemplarily the same law is established/installed also

for the alloy MA3, which during such forms of loading or forging and stamping possesses satisfactory plasticity. Alloy MA5 has lowered/reduced stored up plasticity and hot working by pressure is performed with the soft forms of the stress-strain state (extrusion/pressing in the container, flashless die forging, etc.).

The alloys of magnesium with zirconium (BM65-1, etc.) relate to the group of wrought alloys. Forging and the hot die forging of the alloys of this group are produced also with the soft forms of the stress-strain state with minimum tensile stresses.

High alloys, which possess the low reserve of plasticity, mu be subjected to forging and hot die forging by the method of extrusion/pressing - stamping with the counterpressure, which ensures strain with high main compressive stresses.

Titanium alloys. Commercial titanium (BT1) with the sediment/residue on the press at a room temperature is not destroyed up to deformation 50%; with an increase in the temperature the plasticity is raised and it can be deformed without crack formation at 600° C to 80%, but at 900° C to 90%.

Titanium alloys BT3-1 and BT5 at a room temperature without the translation/conversion into the brittle state are deformed by sta-ic

upsetting to 10-15%. In the case of upsetting on the press with 600°C the permissible deformation composes 60%, and at 900°C - it increases to 90%.

In the case of dynamic deformation under the hammer the plasticity of titanium alloys descends to 10-20%. Thus, for the alloys BT3-1 and BT5 with the sediment/residue under the hammer with 600°C the permissible deformation is equal to 50%, and at 900° - 80%.

Titanium during the cold smith forging by upsetting and by stamping allow/assume the limited deformations. The permissible deformations during cold working can be increased by the use/application of forging in the notched strikers and the stamping in the closed and open dies with the limited broadening, when act the stress-strain states, with which the deformations and tensile stresses are relatively small.

During the hot deformation and, especially, at temperatures of 900°C it is above, when the weakening processes are developed, titanium and titanium alloys have sufficiently high plasticity. From titanium alloys with ductile and hot stamping they are manufactured the complicated on the geometric form of machine part (blade, disks of compressors and other parts).

Titanium and titanium alloys low- and medium-alloyed can be worked by ductile and hot stamping by all methods used, virtually with many forms of loading. These alloys with a change in the stress-strain state, in the limits of the technological processes of forging and stamping used, retain sufficiently high technological plasticity.

For difficultly deformed titanium alloys can be used the semienclosed and closed methods of forging and hot die forging - drawing in the figure faces, upsetting in the plastic shell, flashless die forging with the broadening and without the broadening. Such methods with the soft stressed state allow/assume forging an stamping with the large deformations. Besides the possibility of working with the large deformation and an increase in the technological plasticity, this technological process of working by pressure provides more uniform deformation and obtaining of fine-grained structure and high and uniform mechanical properties.

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The plasticity of titanium and titanium alloys sharply is depressed in the presence on the surface of the alpha-deposited layer. Were carried out experiments on the forging - by upsetting titanium alloys, which had on the surface the remainders/residues of

the alpha-deposited layer.

Bulging test underwent the samples/specimens, in which after the machining of the alpha-deposited layer they remained on the surface along the generatrix of black spot - untreated strips. Samples/specimens were upset on the mechanical crank forging press on the unheated dies/stamps with 1000°C.

Afterward sediments/residues with the degree of deformation are higher 50% on the lateral surface of the blanks, where the alpha-deposited layer remained, wide cracks appeared. The reason for the appearance of cracks on the lateral surface consists in that that more brittle, than base metal, the alpha-deposited layer, it is destroyed as a result of the elongation of the lateral surface of sample/specimen in the beginning of upsetting, forming the network of fine/small cracks. These cracks as stress concentrators, with an increase in the degree of deformation contribute to destruction of base metal. The depth of such cracks is within the limits of 1-2 mm.

Crack formation with the upsetting of samples/specimens made from titanium alloys with the alpha-deposited layer occurs during coating of sample/specimen with consistent grease (the water glass, graphite, etc.). The appearance of cracks in the case of applying consistent grease is explained by the fact that the film of

lubrication between the contact surfaces creates considerable tensile stresses. The brittle alpha-deposited layer of these stress/voltage does not maintain/withstand and is destroyed. On the other side samples/specimens smooth without the cracks are obtained after deformation by upsetting without the lubrication and with the use/application of liquid lubrications - petroleum residue, machine oil, compressor oil, etc.

The lubrications of liquid consistency do not cause the significant magnitude of lateral deformation and tensile stresses.

The presence of the alpha-deposited layer sharply decreases technological plasticity of titanium and titanium alloys. The metal, which has the alpha-deposited layer, is extremely sensitive with the forging and the hot die forging to a change in the stress-strain state with an increase in stresses/voltages and tensile strains. Since, virtually, with all methods of forging and stamping act tensile stresses and deformations, during the heating under the hot machining of titanium and titanium alloys one should avoid the formation of the alpha-deposited layer. This is achieved by heating prior to the forging and the stamping in the reheating furnaces with a neutral or oxidation-free atmosphere. The most adequate/approaching medium for heating of titanium and titanium alloys is argon.

Titanium and titanium alloys are heated in the air-circulating furnaces with coating of blanks with enamels.

Copper alloys have the narrow range of temperatures of forging and hot die forging, low stored up plasticity during the smith forging and high thermal conductivity in the final stage of working, in consequence of which these alloys acquire the lowered/reduced plasticity. Therefore for the copper alloys should be applied the form of loading with the forging and the hot die forging with the smallest possible stretching deformations and the stresses/voltages. Being guided by this, the ingots of copper alloys are deformed predominantly by extrusion/pressing in the containers, and hot die forging is usually produced either with the closed methods of working (flashless die forging), or with the semienclosed methods, or opened, but with the limited broadening. In this case technological processes are applied with the smallest possible number of operations, and in the majority of the cases stamp parts to one pressure or one blow of hammer. For increasing the plasticity of the metal the containers and the dies/stamps are preheated to 300-500°C.

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THERMOMECHANICAL PARAMETERS OF FORGING AND STAMPING.

The thermomechanical parameters of forging and stamping of nonferrous metals and alloys (temperature of beginning and the end of the working; general/common/total of deformations; the permissible deformations, which do not call the decomposition of metal during the working; the deformations, which determine kinetics of the recrystallization of working; the deformation rate; the heating rate, rate of cooling and the stress-strain state of metal during the working), are set to the results of the complex of the tests, given in Table 3, being guided by data of Table 2 and figures 1-95, led in Chapter 1.

Temperatures, speeds and degrees of deformation.

The elevated temperature of the beginning of forging and repeated reheats between the operations make it possible to considerably increase the degree of the deformation of alloys. The high deformation rates with the considerable reduction for one impact/shock cause the premature decomposition of blank not only at low temperatures of the beginning of forging, but even with those increased.

The greatest anisotropy and the lowered/reduced mechanical properties of the pressed semi-finished products are observed during the deformation in limits of 50-75%. In the case of

general/common/total deformation not less than 95% are obtained more uniform mechanical properties along and across the filaments, or the general/common/total level of the properties of the pressed semi-finished products is raised. Therefore during the extrusion/pressing of profiles/airfoils, rods, and also blanks for the forgings and the stampings it is necessary to provide the greatest deformation, which must compose 60-65% for the pressed rods, intended for the forging and the stamping and 95% for the pressed rods and the stampings, designated for manufacturing the machine parts.

Aluminum alloys. Temperature ranges of forging and stamping are determined according to the diagrams of plasticity, the curves of flow and the constitution diagrams of the matching systems of alloys. For the separate aluminum alloys these intervals should be selected in the limits, indicated in Table 4.

Degrees of deformation. The highest mechanical properties and the smallest anisotropy of these properties are obtained during the general/common/total deformation of alloys in 65-75%. Therefore in the case of working by pressure of ingots on the blanks, the forgings, the stampings and other semi-finished products the general/common/total degree of deformation must be minimum.

It follows from the diagrams of the recrystallization of working different aluminum allcys that ultimate strain compose 12-15%. For the purpose of the exception/elimination of the recrystallization of alloys with coarse-grain formation, the forging and their stamping are produced with reduction 15-20% and more for each course of machine.

The permissible degree of deformation for the working stroke of machine, determined from the diagrams of plasticity, for the separate groups of alloys is within the limits, given in Table 2.

Deformation rate. The analysis of the diagrams of plasticity with respect to a change of the permissible deformations of aluminum alloys in the dependence on the rate of working shows that the technological plasticity of alloys noticeably is not depressed with an increase in the deformation rate. Only in separate high alloys upon transfer to the high rates of working the permissible deformations are depressed for each course of machine from 80 to 40%. In addition to this upon transfer from the static ones to the dynamic rates the resistance to deformation of alloys grows/rises 1.5-3 times, depending on their alloying. Therefore aluminum alloys can be worked by ductile and stamping both at the low and high deformation rates.

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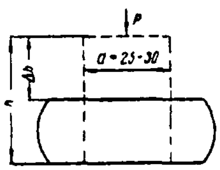
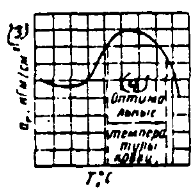
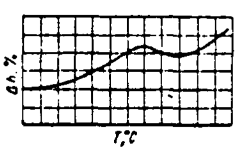
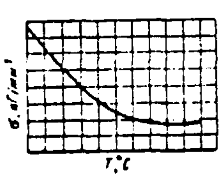
3. Methods for testing steels and alloys for determining of temperatures and other parameters of working by pressure (Korneyev N. I.).

А. Испытание на пластичность свободной осадкой		
	(1) $h \leq 2{,}5d$, $\Delta h = 30 \div 50\%$, $T°$ С — через каждые 25—50° в исследуемом интервале температур	(2) Оценка пластичности производится по появлению первой трещины в деформируемом образце. Определяются T, v, ε.
Б. Испытание на пластичность ударным изгибом		
	(1) Ударные образцы Менаже. $T°$ С — через каждые 25—50° в исследуемом интервале температур	(2) Оценка пластичности производится по максимумам и минимумам на кривых в координатах: $a_н - T°$ С. Определяется T
C. Определение сопротивления деформированию		
а) Определение относительного сопротивления деформированию свободной осадкой (в %)		
	(1) G — вес падающих частей или давление; G = const; H — высота падения; H = const; Δh — степень деформации через каждые 5% в интервале 0—60%; $T°$ С — через каждые 50° в исследуемом интервале температур; d образцов — 10—25 *мм*	(2) Оценка сопротивления деформированию производится по величине осадки (в %) при данной температуре на кривой в координатах: $\Delta h - T°$ С. Определяются T, v, ε
b. *Определение удельного сопротивления деформированию (в кГ/мм²)*		
	(1) Определяется изменением сопротивления деформирования при осадке или других методах обработки месдозами или другими измерительными приборами; Δh — степень деформации при испытании осадкой через каждые 5% в интервале 0—60%; $T°$ С — через каждые 50° в исследуемом интервале температур	(2) Оценка сопротивления деформированию производится по величине его при данной температуре на кривой в координатах: $\sigma - T°$ С. Определяются T, v, ε

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D **Определение критической температуры роста зерна при нагреве (собирательная рекристаллизация)**

(1)

T° C — через каждые 50° в исследуемом интервале температур;

d — диаметр образца 15—30 *мм*.

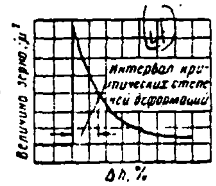
Величина зерна определяется одним из применяемых методов

(2)

Критическая температура роста зерна при нагреве соответствует началу интенсивного роста зерна на кривой в координатах: μ (величина зерна) — T° C.

Определяется T, ε, v

E. **Определение интервала критических степеней деформации при осадке (рекристаллизация обработки)**



(1)

T° C — через каждые 50° в исследуемом интервале температур;

Δh — степень деформации, через каждые 2—5% в интервале 0—60%;

d — диаметр образцов, равный 15—30 *мм*

(2)

Критические степени деформации соответствуют началу и концу интенсивного роста зерна при данной температуре на кривой в координатах: μ (величина зерна) — Δh

Определяются T, ε

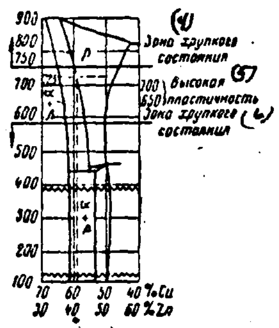
F **Определение фазового состава**

(1)

Фазовый состав определяется по диаграммам плавкости соответствующих систем стали и сплавов

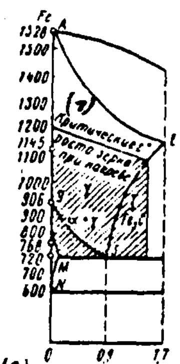
(2) *Диаграмма системы*

Cu—Zn



(3) *Диаграмма системы*

Fe—Fe_3C



(8) *Содержание углерода, %*

(9)

Обработка стали и сплавов давлением по возможности должна производиться в однофазном состоянии, так как при гомогенной структуре отдельные кристаллиты подвергаются более равномерной деформации.

В случае же гетерогенной структуры деформация может быть неравномерной, вследствие различных свойств кристаллитов разных фаз.

Определяются T, ε, v, $\varepsilon_{общ}$.

Key: A. Plasticity test by free upsetting. (1). through each of 25-50° in temperature range being investigated. (2). Evaluation of plasticity is produced on appearance of first crack in sample/specimen being deformed. They are determined.

B. Plasticity test by impact bending. (1). Impact test samples/specimens of Mesnager T°C - through each of 25-50° in the temperature range being investigated. (2). Evaluation of plasticity is produced on maximums and minimums in curves in coordinates: $a_H - T°C$. It is determined by T. (3). cm². (4). Optimum temperatures of forging.

C. Determination of resistance to deformation. a). Determination of relative resistance to deformation by free upsetting (in %). (1). G - weight of falling/incident parts or pressure; G = const; H - fall; H=const; Δh - degree of deformation through every 5% in interval of 0-60%; T°C - through each of 50° in temperature range being investigated; d of samples/specimens - 10-25 mm. (2). Evaluation of resistance to deformation is produced in value of upsetting (in %) at this temperature in curve in coordinates; they are determined. b). Determination of specific resistance to deformation. (1). Is determined by change of resisting deformation with sediment/residue either other methods of working by dynamometers or by other measuring

meters. degree of deformation during testing by upsetting through each 5% in range. through each in temperature range being investigated. (2). Evaluation of resistance to deformation is produced in its value at this temperature in curve in coordinates. they are determined.

D. Determination of critical temperature of grain-growth during heating (collecting recrystallization). (1). Through each of 50° in temperature range being investigated; diameter of sample/specimen 15-30 mm. Grain size is determined by one of the methods used. (2). Critical temperature of grain-growth in heating corresponds to beginning of intense grain-growth in curve in coordinates (grain size). It is determined. (3). grain size. (4). Critical temperature.

E. Determination of interval of critical degrees of deformation with upsetting (recrystallization of working). (1). through each of 50° in temperature range being investigated; degree of deformation through every 2-5% in interval; diameter of samples/specimens, equal to 15-30 mm. (2). Critical degrees of deformation correspond to beginning and end of intense time of ripening of grain at this temperature in curve in coordinates; (grain size) they are determined. (3). Grain size. (4). Interval of critical degree of deformations.

F. Determination of phase composition. (1). Phase composition is

determined according to fusibility curves of matching systems of steel and alloys. (2). Diagram of system. (3). Diagram of system. (4). Zone of brittle state. (5). High plasticity. (6). Zone of brittle state. (7). Critical increase/growth granulating during heating. (8). Content of carbon. (9). Working steel and alloys by pressure as far as possible must be produced in single-phase state, since with homogeneous structure separate crystallites undergo more uniform deformation. However, in the case of a heterogeneous structure the deformation can be nonuniform, as a result of different properties of the crystallites of different phases. They are determined general/common/total.

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However, being guided by the need of increasing the permissible degrees of the deformations of light alloys with the working and the productivity, reduction/descent in the resistance to deformation and the increase in the viscosity/yield of alloys with the filling of the impressions of dies/stamps, during forging and stamping the alloys is more expedient to apply their working on the presses. The tendency of the use/application of static stabilities of deformation for the stamping, the especially large forgings from the light alloys at present are increasingly more fastened. During the extrusion/pressing by extrusion it is necessary to apply high rates, since the productivity and temperature considerably are raised with an increase in the velocity.

For working of wrought alloys it is necessary to apply the closed and semienclosed methods of deformation.

Brittle light alloys, for example the type of system aluminum - beryllium and "SAP", must be worked by the new methods of

extrusion/pressing and stamping with the counterpressure and with the use/application of plastic shells.

The deformation of the ingots of all aluminum alloys, as a rule, must be produced with extrusion/pressing.

The methods of forging and stamping and the type of the stress-strain state depending on the plasticity of alloys must be defined being guided by the classification of the methods of working by pressure due to the stressed and plastic states of the machined alloy.

Magnesium alloys. The temperature intervals of forging and stamping are given in Table 5-7.

With hot treatment the large dependence of the plasticity of magnesium alloys on the temperature is considered by pressure. The high temperature of the termination of deformation makes it possible to utilize the greatest reserve of the plasticity of alloys, but in this case coarser-grained structure is formed, which, in turn, causes decrease in the level of mechanical properties and decrease of the anisotropy of material. The degree of the softening of the stampings from the alloy BM65-1, manufactured on the swaging hammers, is given in Fig. 1, and alloy MA2 in Fig. 2.

4. Temperatures of beginning and end, the permissible degrees and the rate of deformation of the aluminum alloys of ductile and by stamping.

(1) Сплав	(2) Температурный интервал ковки и штамповки в °C		(5) Скорость деформации в м/сек и применяемое оборудование	(6) Допустимые степени деформации в %	
	(3) Начало	(4) Конец		(7) Молот	(8) Пресс
АМц, АМг, АВ, АК6, АК6-1, АД31, АД33	470—420	350	(9) 8—0,3. Молот, пресс	(12) АМц и АМг 80 и более (13)	
				АК6 и АК6-1 (12)	
				(14) Литой 40—50	> 50
				Деформированный (15) 50—65	(16) До 80
Д1, АК8, ВД17	470—440	400	0,3. Пресс (10)	Литой (14) 40	40—60
	450—420	380	8. Молот (11)	Деформированный (15) 50—70	(16) До 80
АК2, АК4, АК4-1 АМг5В, АМг6	470—420 430—400	350 320	8—0,3. (9) Молот, пресс	50—60	(16) Более (13) 60
В92, В95, В96, В93	430—400	350	0,3 Пресс (10)	Литой (14) 30—40	40—50
	400—370	320	8. Молот (11)	Деформированный (15) 50—60	80

Key: (1). Alloy. (2). Temperature interval of forging and stamping in °C. (3). Beginning. (4). End. (5). Deformation rate in m/s and equipment used. (6). Permissible degrees of deformation in %. (7). Hammer. (8). Press. (9). Hammer, press. (10). Press. (11). Hammer. (12). and. (13). and more. (14). Cast. (15). Deformed. (16). To.

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A reduction/descent in the mechanical properties, as is evident from given data, at high temperatures of heating and deformation it occurs as a result of the recrystallization of structure, that also causes

softening.

Exception/elimination from technology of the factors, which cause the softening of material during the hot deformation, is a very important question, since the magnesium alloys MA2, MA2-1, MA3 and MA8 by heat treatment are not strengthened, but the effect of the strain/work hardening alloys MA5 and BM65-1 during the heat treatment is insignificant (Fig. 3).

5. Mode/conditions of forging magnesium alloys on the hammers and the presses.

(1) Марка сплава	(2) Температура ковки в °C				(5) Максимально допустимая степень деформации ва нагрев при осадке в %		(6) Допустимая степень деформации при протяжке в %
	(3) Молот		(4) Пресс				
	(7) Начало	(8) Конец	(7) Начало	(8) Конец	(3) Молот	(4) Пресс	
МА1, МА2, МА8 МА2-1	430 420	340	420 400	300	60 60	80 70	25 15
МА3, МА5 ВМ65-1	400 410	300 340	390 400	280 300	35 80	60 75	— 20
МА13, ВМД1 ВМ17	480 420	400 350	450 400	380 340	50 45	70 65	—

Key: (1). Brand/mark of alloy. (2). Temperature of forging in °C. (3). Hammer. (4). Press. (5). Maximum permissible degree of deformation for heating with sediment in %. (6). Permissible degree of deformation with broach in %. (7). Beginning. (8). End.

6. Temperatures of stamping magnesium alloys on the swaging hammers and the forging presses.

(1) Сплав	(2) Температурный интервал деформации в °С			
	(3) Штамповка на молотах и механических ковочных прессах		(4) Нагартовка на штамповочных молотах	
	Начало (5)	Окончание (6)	Начало (5)	Окончание (6)
МА1, МА2, МА8	430	320	250	230
МА2-1 МА3, МА5	420 400	300	280 —	250 —
ВМ65-1	410	320	270	240
ВМ17 МА13, ВМД1	420 480	350 400	—	—

Key: (1). Alloy. (2). Temperature interval of deformation in °C. (3). Drop forging and mechanical forging presses. (4). Work hardening on swaging hammers. (5). Beginning. (6). Termination.

7. Temperatures of stamping magnesium alloys on the hydraulic presses.

(1) Марка сплава	(2) Температурный интервал деформации в °C			
	(3) Штамповка на гидравлических прессах		(4) Нагартовка	
	(5) Начало	(6) Окончание	Начало (5)	Окончание (6)
МА1, МА2, МА8	420	300	250	230
МА2-1	400		280	250
МА3, МА6	390	280	—	—
ВМ65-1	400	310	270	240
МА13, ВМД1	450	380		
ВМ17	420	390	—	—
МА11	480	380		

Key: (1). Brand/mark of alloy. (2). Temperature interval of deformation in °C. (3). Stamping on hydraulic presses. (4). Work hardening. (5). Beginning. (6). Termination.

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For raising the level of the mechanical properties of stampings one should apply the warm work hardening (final rolling) on the hammers and the presses at temperatures, given in Table 7 and degrees of deformation in limits of 10-15%. An increase in the mechanical properties of the stampings from alloy MA2, manufactured for one transition/transfer with the subsequent work hardening with 230°C on

the hammer, it is shown in Fig. 4. The use/application of a technological operation of final rolling provides the strain/work hardening alloys, which is accompanied by the formation of fine/small homogenous structure.

This data shows that in stampings the mechanical properties are raised with the decrease of grain size.

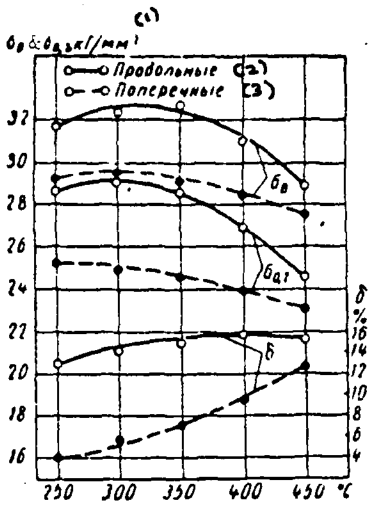

Fig. 1.

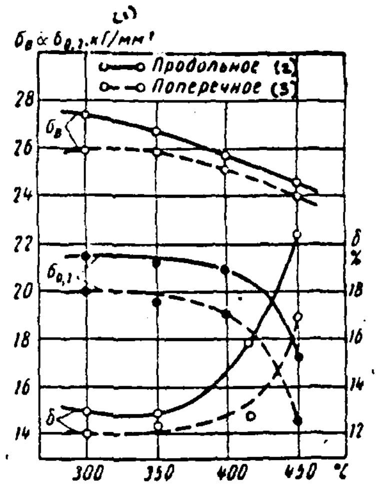

Fig. 2.

Fig. 1. Key: (1). kg/mm². (2). Longitudinal. (3). Transverse.

Fig. 2. Key: (1). kg/mm². (2). Longitudinal. (3). Transverse.

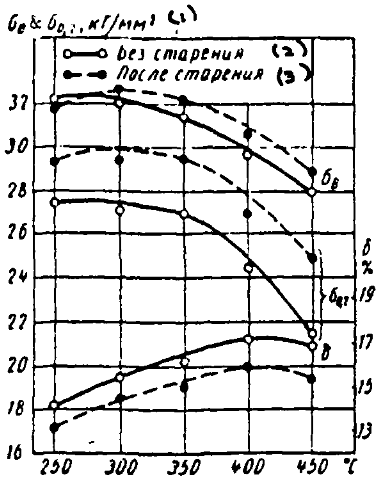

Fig. 3.

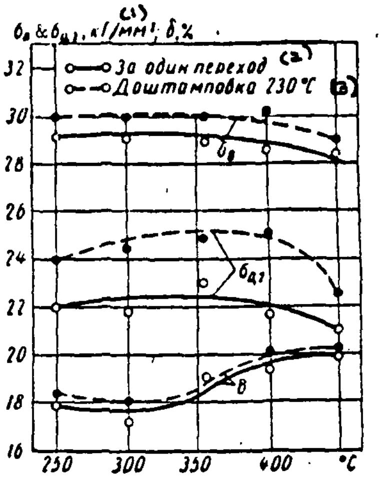

Fig. 4.

Fig. 3. Key: (1). kg/mm². (2). Without aging. (3). After aging.

Fig. 4. Key: (1). kg/mm². (2). For one transition/transfer. (3). Final rolling.

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The best structure of alloy and high mechanical properties are obtained with the press forging with the subsequent final rolling on the hammer with 230-250°C.

A change in the hardness of stampings from alloy MA2 from

deformation temperature and in the dependence on the number of heatings (or number of transitions/transfers during the stamping) shows the character of the softening of alloy (Fig. 5). As a result of prolonged heatings, i.e., the more prolonged determinations of alloy at a temperature, the process of recrystallization pass more completely and magnesium alloys obtains softening.

Taking into account relatively low it stored up the technological plasticity of the majority of magnesium alloys, forging and stamping them should be produced on the hydraulic and crank presses at the lowered/reduced deformation rate. Not lower than 300°C the magnesium alloys virtually little are strengthened in this ca. at a temperature of the end of the deformation and the mechanism of deformation is similar to hot deformation.

Magnesium alloys are considerably better deformed during the working with the low rates; therefore on the hydraulic presses it is possible to obtain stampings of low and large sizes/dimensions with a weight of up to 250-300 kg from all brands/marks of the magnesium alloys being deformed.

For improvement in the viscosity/yield during the deformation and best filling of cavities the stamping should be conducted at temperatures, which correspond to the upper limit,

established/installed for this alloy. In order to create conditions, with which is developed the greatest plasticity, stamping in the closed (flashless) dies/stamps is produced.

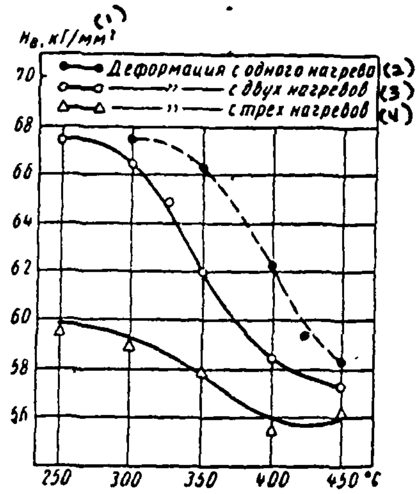

Fig. 5. Key: (1). kg/mm². (2). Deformation from one heating. (3). From two heatings. (4). From three heatings.

8. Degree of deformation for the different diagrams of forging.

(1) Сплав	(2) Температура ковки в °С		(5) Схемы ковки (см. табл. 16 в гл. 5)					
	(3) Начало ковки	(4) Конец ковки	I		II	III	IV	V
			(6) а протяжка без кантовки	(7) б протяжка на квадрат или прямоугольник				
			(8) Максимально допустимые степени деформации (в %) на молотах с весом падающих частей до 2T включительно					
МА2	430	350	55	25	70	80	80	60
МА3	420	340	35	15	55	—	55	—
ВМ65-1	420	300	40	20	65	—	65	—
МА5	380	300	—	—	50	—	—	—

Key: (1). Alloy. (2). Temperature of forging in °C. (3). Beginning of forging. (4). End of forging. (5). Diagrams of forging (see Table 16 V Chapter 5). (6). a broach without turning. (7). b broach to square or rectangle. (8). Maximum permissible degrees of deformation (in %) on hammers with weight of falling/incident parts to 2T inclusively.

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In the process of stamping in the preliminary or final (clean/finishing) dies/stamps on the presses, which ensure the most favorable high-speed/high-velocity conditions for deformation, the degree of deformation is not limited during the optimum temperature conditions.

The deformation (see Table 4 and 8).

Changes in the mechanical properties of forgings from alloy MA2 in the dependence on the degree of stretch are given in Fig. 6, from which it is evident that the blanks of the rod of alloy MA2 of the characteristic of plasticity (δ, a_{H}) are raised with an increase in the drawing, but ultimate strength virtually does not change. An increase in the values of impact toughness and elongation per unit length is explained by an increase in the degree of the deformation of the preliminarily pressed material.

The variety of drawing is the operation of flattening, made in the case of drop forging with the large supply without the turnin or with the turning, during which is smoothed the undulation on the width. In the case of flattening (drawing) on the press during the metal deformation perpendicular to the axis/axle of blank the operation is carried out for one stroke of press.

The diagram of the manufacture of forgings from alloy MA2 by drawing in the direction, perpendicular to the axis/axle of blank, it is shown in Fig. 7. Forging is obtained by the size/dimension 36×380×1050 mm from the pressed blank with the size/dimension 130×1050 mm on the hydraulic press 10000 t for one stroke of press. Heating the measured blanks before the broach was produced in

the electric furnace with 380-360°C, for 5 h. The coefficient of the degree of stretch on the width of blank composed 3.0, and deformation along the height/altitude of blank 72%. The mechanical properties of samples/specimens are shown in Fig. 8.

The amount of total deformation during the forging has a positive effect on the mechanical properties of forgings from the alloys Fig. 9. Ultimate strength and hardness reaches with an increase in the total deformation along the filament of the greatest values. Yield point with an increase in the deformation changes insignificantly and elongation per unit length reaches the maximum values during deformation 50-70%, and during large deformations (80-90%) it is considerably depressed.

Approximately/exemplarily the same laws governing the change in the mechanical properties from the amount of deformation occur, also, in the transverse direction of filament (Fig. 10).

Changes of the mechanical properties of alloy MA2 in the dependence on the degree of deformation during the press forging are given in Fig. 11. All values of strength of mechanical properties with an increase in the deformation grow/rise and plasticity indices are decreased.

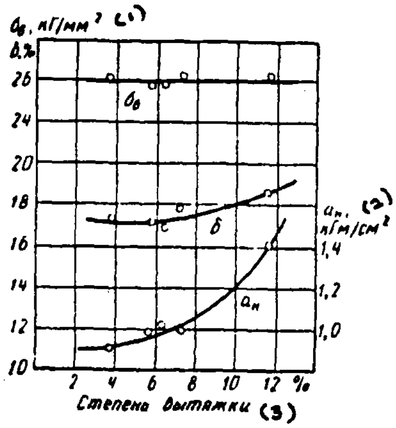

Fig. 6.

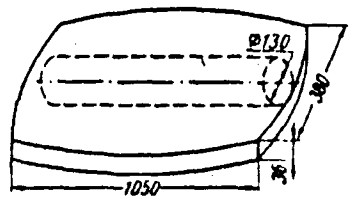

Fig. 7.

Fig. 6. Key: (1). kg/mm². (2). kgfm/cm². (3). Degree of stretch.

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As it follows from the diagrams of the recrystallization of working magnesium alloys, ultimate strain, which call considerable grain-growth, do not exceed 10%.

The rate of deformation (see Table 4). At the low speed of deformation the process of recrystallization has time to noticeably develop only with 350°C, whereas at the high deformation rate recrystallization is developed at a temperature higher than 350°C. For the obtaining of homogenous structure and exception/elimination

of the recrystallization of magnesium alloys, the forging and their stamping are produced with the reduction for the pass more than 15%.

The diagrams of plasticity of magnesium alloys and the degree of the permissible deformations show that the alloys with the increased content of the alloying elements/cells possess the lowered/reduced reserve of technological plasticity and the degree of deformation is determined by the deformation rate.

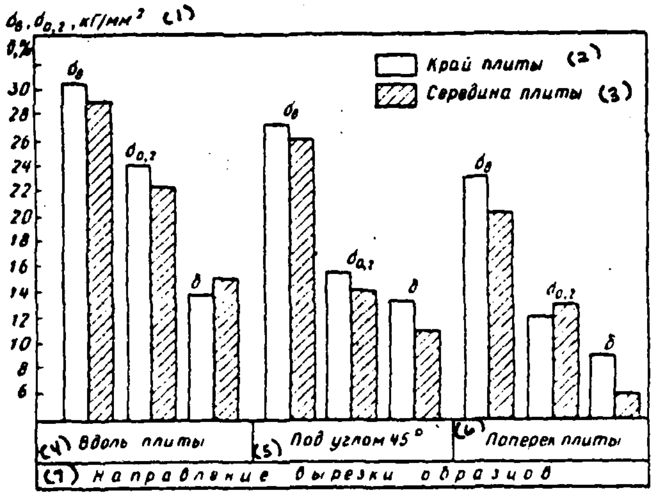

Fig. 8. Key: (1). kg/mm². (2). Kray plate/slab. (3). Middle of plate/slab. (4). Along plate/slab. (5). At angle of 45°. (6). Across plate/slab. (7). Direction of cut of samples/specimens.

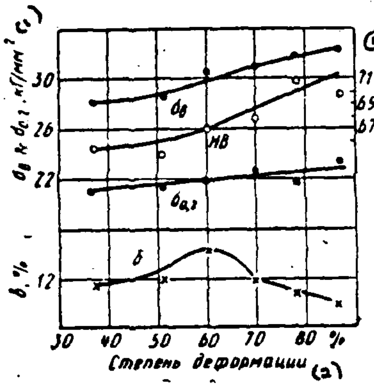

Fig. 9.

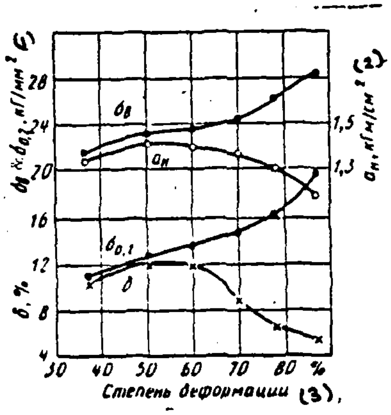

Fig. 10.

Fig. 9. Key: (1). kg/mm². (2). Degree of deformation.

Fig. 10. Key: (1). kg/mm². (2). kgfm/cm². (3). Degree of deformation.

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During the working on the hammer the permissible degree of the deformation of the majority of alloys does not exceed 30-50%, whereas during the working on the hydraulic press their plasticity considerably grows/rises and the degree of deformation can be increased to 70-90%.

Dilute alloys of the type MA1, MA8 are less the speed-sensing of deformation. They are worked well by pressure both on the presses and

on the hammers with the large deformations. Furthermore, the resistance to deformation of alloys at the low speed of deformation is approximately/exemplarily 1.5-2.0 times less in comparison with the working at the dynamic rate.

Titanium alloys. The temperature intervals of forging and stamping are given in Table 9-11.

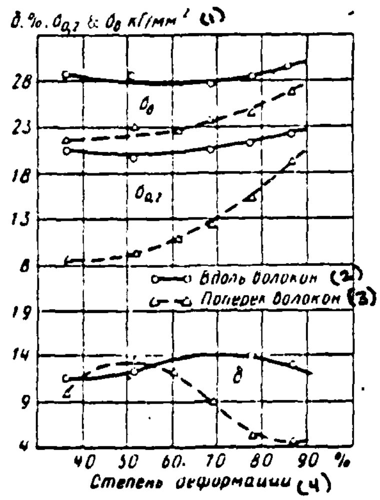

Fig. 11. Key: (1). kg/mm². (2). Along filaments. (3). Across filaments. (4). degree of deformation.

9. The temperature interval of forging and stamping titanium alloys.

(1) Сплав	(2) Температурный интервал в °C			
	(3) Слиток		(4) Предварительно деформированная заготовка	
	(5) Начало (не выше)	(6) Конец (не ниже)	(5) Начало (не выше)	(6) Конец (не ниже)
ВТ1-00 ВТ1-0 ОТ4-0	1000	750	950	700
ОТ4-1		800		
ОТ4	1020	820	1000	800
ОТ4-2	1100	900	1050	
ОТ4 ВТ3-1	1050	850	1020 1000	850
ВТ5	1150	900	1080	
ВТ5-1	1100		1050	800
ВТ6С ВТ6	1050	850	950 980	
ВТ8 ВТ9	1100 1150	900	1020	850
ВТ14	1050	850	950	600
ВТ15	1150 [1]	850	1000 [2] 1050 [2]	850
ВТ16	1000	750	900	700
ВТ18 ВТ20	1150	850	1080 1050	850
ВТ22	1000	850	950	800

Note ; 1. During forging of ingot under the forging hydraulic press the lower limit of forging temperature is permitted to descend against that indicated in the table by 50°C.

2. During forging of preliminarily deformed blank under forging hydraulic press temperature interval of forging can be respectively lowered on 50°C.

3. During forging by the method of double-triple sediment-broach, the temperature of beginning of forging (graph/count 4) with first sediment-broach must be increased for alloys (in °C): BT3-1 to 1030, BT6C to 980, BT6 to 1010, BT8 to 1050, BT9 to 1050, BT14 to 980.

FOOTNOTE [1]. The ingots of alloy BT15 should be deformed only under the press. It is compulsory to begin deformation from the operation of upsetting.[2]. With a diameter of not more than 150 mm. ENDFOOTNOTE.

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The subsequent upsetting of ingot and forging the preliminarily deformed blank for obtaining of more uniform structure and higher mechanical properties should be produced the method two-, three multiple sediment-broach with the replacement of faces and angles with a gradual reduction/descent in forging temperature from the β-region to forging temperature to region $\alpha+\beta$, i.e., heating metal under the deformation to produce above (region β) or is below (region of $\alpha+\beta$) the complete $\alpha+\beta \rightarrow \beta$ transformation of alloy (Table 10).

Degree of deformation. Titanium alloys are deformed extremely unevenly and for obtaining of homogenous structure and mechanical properties the metal must undergo large general/common/total deformation. In contrast to other metallic materials during the insufficient plastic deformation these alloys detect the tendency toward the anisotropy of mechanical properties (difference of the properties between the longitudinal and transverse samples/specimens), which can be considerably reduced, if general/common/total deformation will be greatest. The preferred orientation of crystallites (fibrousness), caused by one-sided deformation, is another of the possible reasons, which call the anisotropy of the properties of semi-finished products from these alloys.

The purity of alloys also has a considerable effect on the anisotropy of properties. The existing methods of melting make it possible to obtain the initial metal of the necessary purity/finish, but subsequent heating and high-temperature deformation in air lead metal to the oxidation and the intense saturation by gases (oxygen, nitrogen, hydrogen) and with other harmful impurities (carbon), which even in a relatively small quantity, decrease mechanical and technological properties, deformability and raise the anisotropy of

the properties of metal.

Investigations showed that at a general/common/total deformation approximately/exemplarily 75-80% and a temperature of forging in interval of 1000-800°C anisotropy of the mechanical properties of an alloy of the type BT1 is obtained thesmallest (Table 12).

10. Temperature of the phase transformation of titanium alloys.

(1) Сплав	(2) t полного $\alpha+\beta \rightleftarrows \beta$ превращения °C ± 20°	(1) Сплав	(2) t полного $\alpha+\beta \rightleftarrows \beta$ превращения °C ± 20°
		ВТ6С ВТ6	940 970
ВТ1-0, ВТ1-00 ОТ4-0	900	ВТ8 ВТ9	990
ОТ4-1 ОТ4 ОТ4-2 ВТ4 ВТ3-1	[illegible] 940 980 980 970	ВТ14 ВТ15 ВТ16	940 800 840
		ВТ18 ВТ20	1000
ВТ5-1 ВТ5	1020	ВТ22	860

Key: (1). Alloy. (2). complete transformation.

11. Temperature of forging and hot die forging of basic titanium alloys.

(1) Сплав	(2) Структура сплава	(3) Температура в °С		
		(4) свободной ковки	(5) штамповки	
			(6) на прессах	(7) на молотах
ВТ1	α	950—700	950—700	1000—700
ВТ5 ВТ5-1		1080—850 1060—850	1100—850 1050—850	1100—850 1080—800
ОТ4-1 ОТ4 ОТ4-2	α+β	1000—800	950—800	1020—800
ВТ4 ВТ6 ВТ8		1020—850 980—850 1020—850	1000—800 950—800 1000—850	1030—850 980—800 1050—850
ВТ3-1		1000—850	980—850	1030—850
ВТ15	β	—	900—870	1000—900

Key: (1). Alloy. (2). Structure of alloy. (3). Temperature in °C. (4). smith forging. (5). stamping. (6). on presses. (7). on hammers.

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A total deformation of approximately 75% provides the decomposition of cast dendritic structure and in this case the mechanical properties of the alloy are raised: increase the limits of strength and viscosity/yield; they are raised (approximately/exemplarily 2 times, in comparison with the cast state) the characteristic of plasticity and the value of impact toughness. During this general/common/total deformation the

mechanical properties of longitudinal and transverse samples/specimens are virtually identical, i.e., the anisotropy of properties is minimum. In this case the microstructure of metal is uniform and characterizes a sufficient study throughout entire section/cut of blank.

Analogous to law in the effect general/common/total deformations on the structure and the mechanical properties are obtained for the alloyed alloys of type BT3-1, BT5, etc. Homogenous structure and minimum values of the anisotropy of properties in these alloys can be achieved/reached during the higher general/common/total deformation of order 90%. With an increase in the alloying of the alloy, the total deformation for achievement of homogenous structure and mechanical properties must be in limits of 85-90%.

During the development of the technological processes of forging and hot die forging and the determination of temperatures and deformations for the separate operations of working by pressure it is necessary to be guided by the volumetric schemes of recrystallization, which show a change of the size of the grain of the metal being deformed in the dependence on the degree of deformation and temperature.

The temperature of the beginning of the recrystallization of

working pure titanium is equal to 600°C. With an increase in the degree of deformation from 10 to 40% it descends to 550°C, while during deformation 80% - to 450-500°C. This temperature is above for titanium alloys. Thus, in alloy BT5 (5% Al) it composes 800°C, in alloys BT3-1, BT8 and BT9 it is equal to 900-975°C.

Ultimate strain, with which occurs a considerable increase in the micrograin, in titanium alloys are within the limits of 2-12%. During the deformations, which exceed 85% on the diagrams of the recrystallization of these alloys the second maximum is observed. The formation of texture during such high deformations makes the crystallographic orientation of the crystallites of very close. The crystallites with the differing little orientation at high temperatures are coalesced according to the law of the coalescence of crystals. The second maximum is formed as a result of the development of the process of the collecting recrystallization, when metal undergoes high deformations.

In accordance with the diagrams the recrystallizations of perfecting deformation for each course of machine during the forging and the stamping must exceed critical ones and be taken as the equal to 15-20% and more, but not higher than 85%. It also follows from the diagram of the recrystallization of working titanium alloy BT3-1 that the interval of ultimate strain is expanded with an increase in the temperature of forging and stamping and the maximums of ultimate strain increase.

12. Anisotropy of mechanical properties of alloy BT-1.

(1) Исходное состояние	(2) Величина общей деформации в %	(3) Механические свойства				
		σ_b	σ_s	δ	ψ	(6) $a_н$
		в кГ/мм² (4)		(5) в %		в кГм/см²
(7) Литой слиток	—	32,5—40,2	27,1—31,7	12,0—15,0	17,1—20,6	1,9—1,3
(8) Кованое продольное направление волокна	75—80	43,5—46,5	34,9—35,9	28,4—24,8	48,0—28,0	2,6—2,5
(9) Кованое поперечное направление волокна		44,4—53,5	34,5—44,5	22,0—22,4	39,8—40,0	2,5

Key: (1). Initial state. (2). Amount of general/common/total deformation in %. (3). Mechanical properties. (4). kg/mm². (5). in %. (6). kgfm/cm². (7). Cast ingot. (8). Forged longitudinal direction of filament. (9). Forged transverse direction of filament.

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From this it is possible to draw the conclusion that the forging and stamping pure titanium and titanium alloys at too high temperatures leads to an increase of grain size in the forgings and the stampings. Coarse-crystalline structure in the forgings and the stamped/die-forged machine parts depresses their mechanical properties. Being guided by such a kinetics of grain-growth during forging and stamping titanium alloys at different temperatures of working, the temperature of the beginning of forging and hot die forging the two-phase alloys of higher 920-980°C is not applied in

practice.

In this case one must take into account that in the case of the incomplete completion of the recrystallization of working in the process of forging and stamping, and also during the cooling from the temperatures of the end of the working, the softening completely is not removed and the technological plasticity of alloys is depressed. For the purpose of the retention/preservation/maintaining plasticity one ought not to allow/assume reduction/descent in the temperature of the end of forging and stamping these alloys in lower than the temperatures of the beginning of recrystallization. Consequently, kinetics of recrystallization determines the plasticity of metal during the working.

On the other hand, and the temperature, and the deformations in the process of forging and stamping must be accepted in such limits, which would create the thermomechanical conditions of obtaining the prescribed/assigned structure. The structure can be either not recrystallized with the deformed crystallites in the direction of the metal flow, which have strain hardening, or recrystallized, in which the strain hardening virtually completely is removed/taken in the process of recrystallization and crystallites acquire rounded form.

By the form of that obtaining during the forging and the

stamping by macro- and microstructures are determined the mechanical properties of forgings and stampings from titanium alloys.

Consequently, by the degree of the development of the process of the recrystallization of working during the forging and the stamping, the cooling after working by pressure and the heat treatment are determined the technological plasticity, macro- and microstructure and the mechanical properties of wrought titanium alloys. This must be considered during the development of the technological processes of forging and stamping.

Deformation rate. With the forging and drop forging in many instances the recrystallization of working does not manage to be completed. The plasticity of titanium alloys being deformed at this rate is depressed. During the manufacture of forgings complex-shape on the configuration and drop forgings the metal can convert/transfer into the brittle state and its plasticity of the impression of dies/stamps are filled incompletely with the decrease. An underspeed of deformation during the forging and the stamping and the use/application of presses instead of the hammers proves to be from the technical side more justified. The recrystallization of treatment under such thermomechanical conditions flows/occurs/lasts with the large completion and the plasticity of metal in the process of forging and stamping in effect is not depressed.

Kinetics of the recrystallization of working during the forging and to stamping shows that plasticity, the structure and the mechanical properties of the metal being deformed are determined by the temperature-velocity conditions for working and by the degree of deformation accepted. The degree of deformation for each course of machine should be applied higher, but the rate of deformation is too great. In connection with this stamping titanium alloys it is necessary to produce on the hydraulic and crank presses at temperatures not higher than 950-980°C.

Copper alloys. The temperature intervals of forging and stamping (Table 13). Copper possesses the greatest plasticity in the range of temperatures of 800-950°C. At these temperatures copper yields well to forging, hot die forging and extrusion/pressing. It is expedient to produce forging of copper at 820-860°C. With the optimum temperatures of forging and hot die forging they are: 730-820°C for brass Л59, 750-850°C for brass Л62.

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As a result of the fact that during the extrusion/pressing the stressed state softer in comparison with the ductile and hot

stamping, the range of temperatures of extrusion/pressing can be expanded to 650-850°C. The temperature of the hot machining of brass Л68 is located in interval of 650-830°C. The greatest plasticity of alloys at temperatures indicated is connected with the fact that these alloys at such temperatures have the phase composition, which consists of $\alpha+\beta$ phases or only of a β-phase, which possess the sufficiently high reserve of plasticity.

Bronze Бр. АЖ 9-4 has highest plasticity with 850°C, and the permissible range of temperatures of working alloy must be maintained/withstood within limits of 800-900°C, when bronze is in single-phase state. Since in the process of stamping occurs the m e intense cooling of the metal being deformed by the walls of die/stamp, forging this bronze is produced at 850°C, and hot die forging with 900°C. Hot working by the pressure of copper alloys at higher temperatures is accompanied by a decrease in the plasticity because of the excessive increase/growth in brass and bronze of the crystallites of beta-phase and by weakening the strength of crystallites. With a temperature decrease, beginning with 450°C or lower, formation into brass little plastic β'-phase, plasticity of these alloys during the working sharply is depressed. Furthermore, deformation at such temperatures leads to the considerable drag-rise characteristics to deformation. Thus, the working of brass Л59-1 at 600°C with reduction 40% causes an increase of the resistance to

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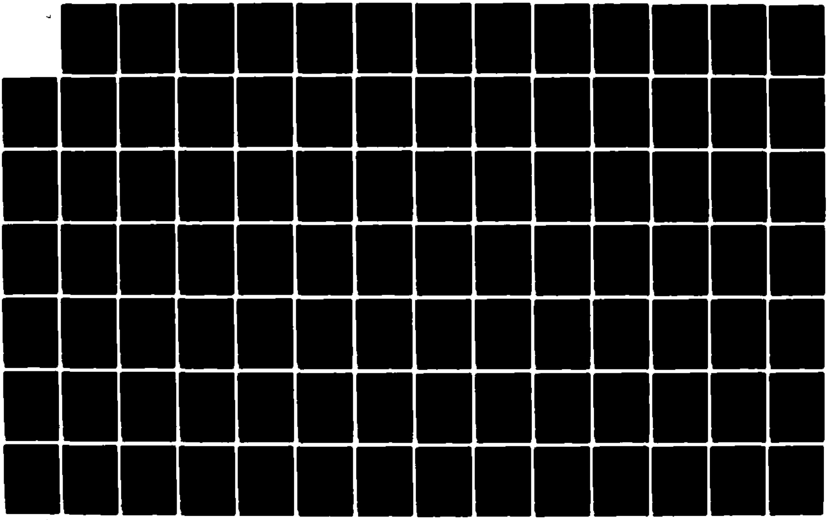

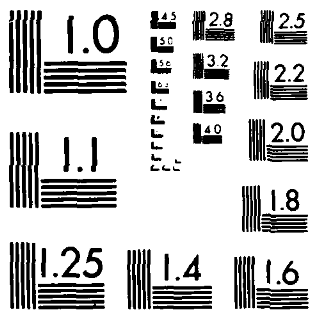

MICROCOPY RESOLUTION TEST CHART
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deformation already 4 times. An analogous reduction/descent in the plasticity is observed also in bronze Бр. АЖ9-4. The lower plasticity of brass and bronze with a temperature decrease is explained, just as has already been indicated above, by the presence of brittle zones in brass with 300-700°C, and in bronze Бр. АЖ 9-4 at 650-700°C.

13. Temperatures of the hot deformation of copper alloys.

Сплав (1)	Температура в °C (2): ковки-штамповки (3)	Температура в °C (2): прессования (4)
Медь (5)		
М1, М2, М3	800—950	775—925
Латунь (6)		
Л96	700—850	830—880
Л90	800—900	830—900
Л80, Л85, Л70	—	820—870
Л68	700—850	750—830
Л62		650—850
ЛА 77-2	—	700—830
ЛАЖ 60-1-1		700—750
ЛАН 59-3-2	700—750	
ЛН 65-5	650—850	750—850
ЛЖМц 59-1-1	650—820	650—750
ЛМц 58-2	600—750	625—700
ЛМцА 57-3-1	600—730	
ЛО 90-1	850—900	850—900
ЛО 70-1	650—750	650—750
ЛО 62-1	680—750	700—750
ЛС 60-1	700—820	780—820
ЛС 59-1 ЛС 59-1В	640—780	640—780

Сплав (1)	Температура в °C (2): ковки-штамповки (3)	Температура в °C (2): прессования (4)
Бронза (7)		
Бр. А5	750—900	830—880
Бр. А7	780—900	850—900
Бр. АМц 9-2	800—960	750—850
Бр. АЖ 9-4	750—900	
Бр. АЖМц 10-3-1,5		700—850
Бр. АЖН 10-4-4	800—900	830—880
Бр. В2	650—800	720—860
Бр В2,5	720—800	
Бр КМц 3-1	600—780	825—875
Бр КН 1-3	800—910	850—900
Бр. ОФ 4-0,25		750—800
Бр. ОФ 6,5-0,4		680—770
Бр. Х 0,5	800—920	—
МНц 15-20		750—825
НМЖМц 28-2,5-1,5		850—950

Key: (1). Alloy. (2). Temperature in °C. (3). forging stamping. (4). extrusion/pressing. (5). Copper. (6). Brass. (7). Bronze.

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Degree of deformation. The process of the recrystallization of copper alloys with coarse-grain formation proceeds in the case of hot machining during ultimate strain, which for these alloys are within the limits of 10-15%. The recrystallization of the treatment with the formation of fine/small grain occurs when forging and stamping are

accomplished/realized during the higher supercritical deformations and at established/installed temperatures of working for copper of 800-950°C and for brass and bronze of 750-850°C. On the basis of this stamping copper and copper alloys must be produced with the reduction with that exceeding 15% for each course of machine.

Deformation rate. The narrow range of temperatures of forging and stamping of copper and copper alloys necessitates the performing of working by their pressure with the smallest number of operations and transitions/transfers, i.e., with the closed methods. During the working by the closed impedance methods to deformation grows/rises. On the other hand, an increase in the rate of working also increases the resistance to deformation. Taking into account these laws governing the change of the resistance to deformation in the dependence on the stressed state of metal and deformation rate, stamping should be conducted predominantly on the crank and friction presses; is allowed/assumed also working at the dynamic rate and on the hydraulic presses.

Heating blanks.

The process of heating measured blanks must provide the optimum rate of reaching/achievement of the required temperature in the blanks and its sufficiently uniform distribution over the section/cut. The

higher the rate of heating (i.e. the less its duration), the more economical (profitable) the heating is. However, during the excessively rapid heating as a result of considerable temperature gradient over the section/cut of blank in the metal thermal stresses can appear. Therefore, the allowable speeds of heating are distinguished technically possible and.

The heating time can be calculated according to the following formula, derived by theoretical method.

$$t = \frac{S^2}{2a\Delta t k_1}\left(t_{кон}^{ср} - t_{нач}^{ср}\right),$$

where t - heating time; $t_{кон}^{ср}$ and $t_{нач}^{ср}$ - average/mean final and init i temperatures of metal; Δt - difference in the temperatures in the section/cut of the heated blank in the constant velocity of the heating

$$\Delta t = \frac{c_x S^2}{2k_1 a} = t_{пов}^{нач} - t_{цен}^{нач},$$

where the rate of heating $c = \frac{t_{кон} - t_{нач}}{t}$; S - thickness of the plate of the heated metal; α - rate of heating surface in m^2/h, determined to to diagram (page 404, Fig. 135, metallurgical furnaces, Metallurgizdat, 1951) k_1 - shape factor (for different shapes of bodies it is selected according to table).

With the repeated operations of forging the time of heating the

blanks, which cooled off to the lower limit of the established/installed temperatures, can be decreased by 50%.

Cooling forgings.

Since the light alloys have high thermal conductivity, their cooling after working by pressure is carried out in the open air.

Rate of cooling after hot working by pressure is divided into two period: to the temperatures of the beginning of recrystallization and from the temperatures it is lower than the temperatures of the beginning of recrystallization.

The first period can be carried out with the high rate. The thermal stresses are small, phase transformations only begin as a result of the course of recrystallization processes in this temperature range, volumetric changes and stresses/voltages appearing from them reach low value.

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Strain hardening with the course of recrystallization is absent and the plasticity of metals and alloys sufficiently high. Therefore in the first cooling-down period metal is located in such state, which

cannot transfer it into the brittle state.

The second period must flow/occur/last with given speed. In the area of such temperatures at high rate of cooling the thermal stresses and the stresses/voltages, which appear from the phase transformations, can be considerable, since in the cooling process in the range of these temperatures the metal passes through critical points. Can be formed the stresses/voltages of the significant magnitude from the pressure of hydrogen in steel, when rate of cooling is determined for the forgings and the stampings made of steel. Rate of cooling during this period one should determine by analytical or experimental methods and strictly check under the established/installed conditions.

By analytical method rate of cooling is determined on the basis of the following calculations: the temperature differential of deformation in the process of working by pressure; thermal stresses; residual stresses/voltages; stresses/voltages from the volumetric changes during the phase transformations, the nonuniform deformation and the strain hardening: the determination of rate of cooling, which ensures the diffusion of hydrogen made of steel and the exception/elimination of the formation of flocs (for the case of cooling steel).

The calculation of a temperature drop of deformation in each given moment in the cooling process is performed for determining the temperature, beginning with which the beginning of cooling, according to the formula

$$Z_{ж} = \frac{t_{н} - t_{к}}{t_{н}} \cdot \frac{g}{F},$$

where $Z_{ж}$ - time of cooling forging or stamping in the minutes from temperature $t_{н}$ to temperature $t_{к}$; begins g - weight of forging or stamping in kg; F - middle surface of forging or stamping in the process of drawing, upsetting or stamping.

This temperature can be set, also, according to the indices of a pyrometer if it is determined for current production.

The calculation of thermal stresses is produced with the following methods.

If cylinder with an initial difference in temperatures $\Delta t_{н}$ is heated with a constant velocity of $C^{\circ}_{н}$ per hour, then the value of longitudinal stresses is determined from the equation

$$\sigma_z = \frac{\beta E}{1-V}\left[\frac{c_{н}R^2}{8a}\left(1-2\frac{r^2}{R^2}\right)+\right.$$
$$\left.+\left(\frac{c_{н}R^2}{a}-4\Delta t_0\right) f\left(\frac{a\tau}{R^2};\ \frac{r}{R}\right)\right],$$

where β - coefficient of linear expansion; E - modulus of elasticity; V - Poisson relation; $c_{н}$ - heating rate; R - radius of cylinder; a -

thermal diffusivity 0.02 m^2/h; r - coordinate or the distance of heat flux from the surface of the heated metal; Δt_0 - initial difference in the temperatures; f - designation of the sum of infinite series; τ - time interval.

Investigating the solutions of this equation, it is possible to show that with the sufficiently wide interval of time, namely, with $\tau \geq 0.5R^2/a$, function f as a result of the smallness of its value it is possible not to take into consideration.

For the same heating of plate the equation of thermal stress takes the form:

$$\sigma_y = \sigma_x = \frac{\beta E}{1-V}\left[\frac{c_H S^2}{6a}\left(1 - 3\frac{x^2}{S^2}\right) + \left(\frac{c_H S^2}{a} - 2\Delta t_0\right) f\left(\frac{a\tau}{S^2};\ \frac{x}{S}\right)\right],$$

where S - thickness of plate; x - coordinate or the distance of heat flux from the surface of the heated metal.

In this equation also at certain sufficiently high value $\tau \geq S^2/a$ function f takes such low values, that it can be disregarded/neglected.

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Residual stresses/voltages in the cylindrical rods and the thick-walled ducts/tubes/pipes are determined by removing/taking of the concentric words, measurement of the deformations of duct/tube/pipe or rod and the calculations of stresses/voltages conduct according to the formulas:

longitudinal

$$\sigma_e = \frac{E}{1-\mu^2}(F_{\text{нар}} - F)\frac{de_l + \mu de_o}{dF};$$

tangential

$$\sigma_\theta = (F_{\text{нар}} - F)\frac{E}{1-\mu^2}\left(\frac{de_o + \mu de_e}{dF}\right);$$

radial

$$\sigma_r = \frac{E}{1-\mu^2}\cdot\frac{F_{\text{нар}} - F}{2F}(e_o + \mu e_l),$$

in which E - Young's modulus; μ - Poisson's coefficient; $F_{\text{нар}}$ - area on the external diameters; F - area of the internal section/cut of duct/tube/pipe; e_l - relative change in the length; ϵ_o - relative change in the diameter; R - inside radius of duct/tube/pipe (for rod R=0).

Residual stresses/voltages in the disks are determined via the cut of rings, measurement of their diameters and computation of residual stresses/voltages (tangential - σ_θ and radial σ_r) according to the formulas (longitudinal stresses in the disks with the cut/section they are removed/taken).

$$\sigma_r = \frac{\delta}{\rho_н}(\sigma_\theta - \sigma_r),$$

where δ - thickness of ring, $\rho_н$ - radius of external filament;

$$\sigma_\theta = \mu\sigma_r + \frac{\Delta D}{D}E;$$

ΔD - change in the diameter of ring, they accept negative with the decrease of diameter after cutting.

If temperature and residual stresses in the sum do not exceed the yield point of malleable alloy, then the presence of such stresses/voltages is admissible and the stresses/voltages of this value cannot cause crack formation during the cooling after forging and hot die forging.

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Chapter 3.

ELEMENTS OF CONSTRUCTION OF FORGINGS AND TOOLS, POWER OF MACHINES.

The hydraulic and crank presses, which ensure the mo: favorable high-speed/high-velocity conditions for deformation, are [illegible] equipment for forging of nonferrous metals and alloys on their basis. However, aluminum, copper, titanium and magnesium alloys MA2 and BM65-1 can undergo forging, also, on the hammers.

The basic operations of forging are upsetting, drawing, piercing, bending and cutting.

SEDIMENT/RESIDUE.

To upsetting (Fig. 1) they apply:

for obtaining the forged blanks with the considerable transverse sizes/dimensions at the relatively low height (pinions, disks,

flanges) of the initial blanks of smaller cross section;

as the preliminary operation before the piercing with manufacture of ring-shaped blanks;

as preliminary operation for the decomposition of cast structure and corresponding increase in the mechanical properties;

for increasing the degree of reduction during the subsequent drawing.

The mean diameter of blank at any moment of settling (Fig. 1.

$$d = d_0 \sqrt{\frac{h_0}{h}}.$$

Degree of deformation with the sediment/residue

$$\varepsilon = \frac{h_0 - h}{h_0} = \frac{\Delta h}{h_0}$$

or

$$\varepsilon = 100 \frac{h_0 - h}{h_0} = 100 \frac{\Delta h}{h_0} \%.$$

Main deformation

$$\delta = \ln \frac{h_0}{h} = -\ln (1 - \varepsilon).$$

With $h_0/h<1.2$ or $\epsilon<20\%$ with a sufficient for practical purposes precision/accuracy it is possible to consider that $\delta=\epsilon$.

Misaligned volume $V_e = V \ln \frac{h_0}{h}$; with $h_0/h<1.2$ (with $\epsilon<20\%$) with the error in limits of 10% it is possible to consider that $V_e = V \frac{\Delta h}{h_0}$, where V - volume of the upset blank.

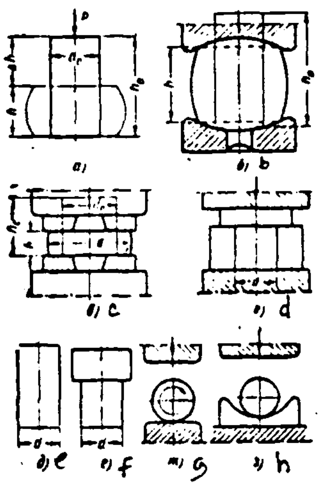

Fig. 1. Diagram of upsetting.

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The effort/force, necessary for the upsetting in the hot state under the press (see Fig. 1),

$$P = m\sigma_e F,$$

where m - coefficient, depending on the conditions for upsetting $m=1+\mu/3\cdot d/h$; μ - coefficient of friction in this case $\mu=0.5$; σ_e - limit of the strength of material at a temperature of upsetting (Table 1); F - cross-sectional area of the upset blank; d and h - respectively diameter and the height/altitude of the upset blank.

Example. To determine effort/force of press for upsetting of blank of the alloy AK6, d_0=200 mm and h_0=480 mm to a height h=250 mm.

The mean diameter afterward upsetting

$$d = d_0 \sqrt{\frac{h_0}{h}} = 200 \sqrt{\frac{480}{250}} \approx 280 \text{ мм}$$

Upsetting temperature by 400°C; μ=0.5; $\sigma_{s\,400°}=6$ kg/mm².

$$m = 1 + \frac{\mu}{3} \cdot \frac{d}{h} = 1 + \frac{0,5}{3} \cdot \frac{280}{250} \approx 1,2;$$

$$F = \frac{\pi d^2}{4} = \frac{\pi\, 280^2}{4} = 61\,544 \text{ мм}^2;$$

$$P = m\sigma_s F = 1,2 \cdot 6 \cdot 61\,544 = $$
$$= 443\,117 \text{ kgf}.$$

Consequently, upsetting can be produced on the press by effort/force 500 t.

Required energy of impact/shock for hot upsetting

$$L_м = \frac{A_к}{\eta_y},$$

where η_y — efficiency of impact/shock, equal to 0.8-0.9; $A_к$ — work of deformation for the latter/last impact/shock;

$$A_к = \omega m \sigma_s \varepsilon_к V;$$

ω - speed factor. Under the percussive influence of forces ω=3-4; $\varepsilon_к$ — degree of deformation, taken for the latter/last impact/shock.

Usually it they select less than the critical. For the aluminum alloys it is possible to accept $\varepsilon_к$= 0.03-0.05.

For obtaining A_{κ} in the kgfm one should substitute σ_{ϵ} in kg/mm²; V in cm³.

The necessary number of blows of the hammer

$$n = \frac{A}{\eta_0 L_{\kappa}},$$

where A - work of deformation for entire process of upsetting;

$$A = \omega m_1 \sigma_e V;$$

$$m_1 = \ln\frac{h_0}{h} + \frac{2}{9}\mu\frac{d_0}{h_0}\left[\sqrt{\left(\frac{h_0}{h}\right)^3} - 1\right]$$

(to substitute L_{κ} in the kgfm, σ_{ϵ} in kg/mm², V in cm³).

Example. To determine the weight of the falling/incident par of the hammer for upsetting of blank of the alloy AK6 to a height h=100 mm; d=160 mm; h_0=300 mm. The mean diameter after upsetting

$$d = d_0\sqrt{\frac{h_0}{h}} = 160\sqrt{\frac{300}{100}} = 270\ \text{мм}.$$

1. Tentative values of limit of strength $\sigma_в$ in kg/mm² of some alloys at forging temperatures (according to graphs [24, 47]).

Сплав	Температура в °C				
	300	350	400	450	500
Алюминиевые сплавы					
АМц	—	8	5	4	3,5
Д16		14	9	5	—
АК6	15	9	6	4,5	2
АК8	14	13	9	7,5	—
В95	—	7,5	5,5	3,5	
АК4		6	4	3	2
Магниевые сплавы					
МА2	7	5	3,5	2	—
МА3	12	6	4	—	
ВМ65-1	4	3	2	1,5	
ВД-17	—	5	2,5	2	1,5

Сплав	Температура в °C				
	700	800	900	1000	1100
Медные сплавы					
Бр. АЖ 9-4	5,7	3,8	—	—	—
Бр. Б 2	10	4,0			
Титановые сплавы					
ВТ1	7,5	3,5	2,5	—	1
ВТ3	22	7,5	7	2,5	2
ВТ3-1	23	10	7,5		
ВТ4	14	11	5	2	—
ВТ5	25	10	6	3	2
ВТ6	28		5		

Key: (1). Alloy. (2). Temperature in °C. (3). Aluminum alloys. (4). AMts. (5). Magnesium alloys. (6). Copper alloys. (7). Br. (8). Titanium alloys.

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Upsetting temperature 400°C; μ=0.5; $\sigma_в=6$ kg/mm²;

$$m = 1 + \frac{\mu}{3} \cdot \frac{d}{h} = 1 + \frac{0,5}{3} \cdot \frac{279}{100} = 1,465;$$

$$V = \frac{\pi d_0^2 h_0}{4} = \frac{\pi \cdot 16^2 \cdot 30}{4} = 6050 \text{ см}^3.$$

With ω=3 and $\varepsilon_к = 0,04$

$$A_к = \omega m \sigma_в \varepsilon_к V = 3 \cdot 1,465 \cdot 6 \cdot 0,04 \times$$

$$6050 = 6383$$ the kgfm.

Accepting $\eta_y=0,8$, we obtain

$$L_м = \frac{A_к}{\eta_y} = \frac{6383}{0,8} = 7978 \text{ kgfm.}$$

Average speed v_0 of the ram of steam-air swage at the moment of impact/shock is equal to 6.5 m/s, then

$$L_м = \frac{Gv_0^2}{g2} = \frac{G6,5^2}{9,81 \cdot 2} = 2,15G,$$

where G - weight of the falling/incident parts of the hammer;

$$G = \frac{L_м}{2,15} = \frac{7978}{2,15} = 3700 \text{ kgf.}$$

We select hammer with G=3000 kgf.

Then $L_м=3000 \cdot 2,15=6450$ kgfm;

$$m_1 = \ln\frac{h_0}{h} + \frac{2}{9}\mu\frac{d_0}{h_0}\left[\sqrt{\left(\frac{h_0}{h}\right)^3} - 1\right] = \ln\frac{300}{100} + \frac{2}{9}\cdot 0,5\cdot\frac{160}{300}\left[\sqrt{\left(\frac{300}{100}\right)^3} - 1\right] = 1,78;$$

$$A = \omega m_1 \sigma_в V = 3 \cdot 1,78 \cdot 6 \cdot 6050 = 193\,600 \text{ кГм; (1)}$$

$$n = \frac{A}{\eta_y L_м} = \frac{193\,600}{0,8 \cdot 6450} \simeq 85 \text{ ударов. (2)}$$

Key: (1). kgfm. (2). impacts/shocks.

The height/altitude of initial blank for the upsetting must be not more than 2.5 of its diameter. With $h_0>2.5\ d_0$ y of blank appears the tendency toward the maximum bend, whose elimination is connected with accomplishing of additional operations.

To upsetting of cylindrical blanks on smooth faces they apply with the work under the press or the hammer, as a rule when piercing is the following operation.

The height/altitude of the blanks, upset under the hammer, is limited to the course of moving elements. If h_0 - height/altitude of initial blank, and H - complete course of the moving elements of the hammer, then it is necessary for the correct flow of the process of upsetting, in order to $(H-h_0)>0.25\ H$.

To upsetting of blank with the stem (Fig. 1b) they apply with the work under the press; when drawing is the following operation. In this case the ends/faces of blank after upsetting are convex, which prevents the formation of concave ends/faces during the subsequent drawing of blank.

To upsetting in the backing rings (Fig. 1c) they apply for manufacturing the blanks of gears, disks and other forgings with the stepped part of the small diameter, but the considerable

height/altitude. In this case drawing out of the ends of the blank to the diameter of stepped part is not rational in connection with the large difference in the diameters of initial blank and stepped part of the forging. The internal surfaces of backing rings are made with draft/gradient of 5-7°, which provides the easy removal/output of rings from the forging. One backing ring is utilized for the forging with one lug.

To upsetting in the ring (Fig. 1d) they apply for the forgings of the type rod with the boss, when the diameter of initial blank can be selected equal to the diameter of rod or somewhat smaller (Fig. 1e), and also if blank can be preliminarily drawn out to the diameter of rod (Fig. 1f).

Finishing operation - rolling on the diameter make for the correction of the barrel-shape form of the lateral surface of forging after upsetting by taps of hammer or by the presses of press during the rotation of the blank, established/installed to the edge/fin, around the axis/axle (Fig. 1g). Sometimes in this case apply backings/blocks or swages/snaps (Fig. 1h).

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DRAWING.

Drawing is accomplished/realized by a series/row of consecutive squeezings. The parameters of each n squeezing they are (Fig. 2):

reduction - reduction ratio or the degree of deformation on the height/altitude

$$\varepsilon_n = \frac{h_{n-1} - h_n}{h_{n-1}} = \frac{\Delta h_n}{h_{n-1}};$$
$$\Delta h_n = h_{n-1}\varepsilon_n;$$
$$h_n = h_{n-1}(1 - \varepsilon_n);$$

the degree of the reduction

$$I_n = \frac{F_{n-1}}{F_n} = \frac{l_n}{l}; \quad l_n = lI_n;$$
$$\Delta l_n = l_n - l = l(I_n - 1).$$

After one squeezing throughout entire length l_{n-1} of blank its complete length

$$l_n = l_{n-1}I_n; \quad \Delta l_n = l_n - l_{n-1} =$$
$$= l_{n-1}(I_n - 1);$$

relative broadening or the degree of deformation on the width

$$\varepsilon'_n = \frac{a_n - a_{n-1}}{a_{n-1}} = \frac{\Delta a_n}{a_{n-1}} =$$
$$= \frac{1}{I_n(1 - \varepsilon_n)} - 1;$$

whence $\Delta a_n = a_{n-1}\varepsilon'_n$ or

$$\Delta a_n = a_{n-1}\left[\frac{1}{I_n(1 - \varepsilon_n)} - 1\right];$$
$$a_n = a_{n-1}(1 + \varepsilon'_n) = a_{n-1}\frac{1}{I_n(1 - \varepsilon_n)};$$
$$a_n = \frac{F_n}{h_n};$$

conversion factor or the ratio of the width of forging to its height/altitude after this squeezing

$$\varphi = \frac{a_n}{h_n} = \frac{a_{n-1} + \Delta a_n}{h_{n-1} - \Delta h_n} = \frac{a_{n-1}}{h_{n-1}} \cdot \frac{1}{l_n (1 - \varepsilon_n)^2}.$$

The value of squeezing during the drawing is selected such that if necessary for the subsequent turning coefficient φ would not exceed 2-2.5 (Fig. 2c).

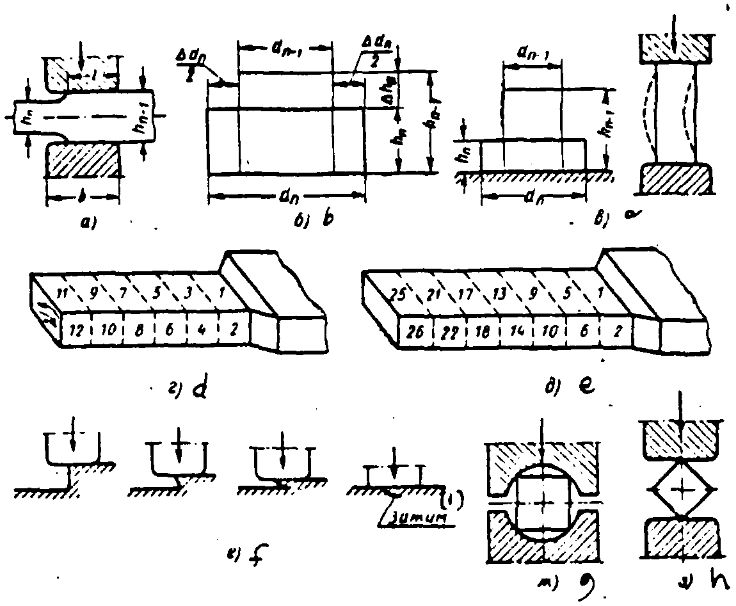

Fig. 2. Diagram of drawing.

Key: (1). clamp.

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The degree of reduction for several squeezings is equal to the product of the degrees of reduction for each squeezing. Degree of reduction for entire operation

$$l = \frac{F_0}{F_{\text{кон}}} = l_1 l_2 \dots l_{n-1} l_n;$$
$$l_{\text{кон}} = l_0 l; \quad \Delta l = l_{\text{кон}} - l_0 = (l - 1) l_0.$$

The less the broadening and the greater the elongation of blank with each squeezing, the more the degree of reduction, i.e., the more

intensely proceeds the process of drawing. The intensity of drawing increases with the decrease of width b of face or rate l of feed, and also the decrease of the coefficient of friction. The intensity of drawing grows/rises with the use/application of the carved or rounded faces, and also the swages/snaps.

Rules of drawing. Drawing without the swages/snaps, directly under the faces can be produced with the turning on 90° (Fig. 2d) or along the helix (Fig. 2e). The second method is applied during forging of the alloys, which have the low rate of recrystallization at forging temperature.

With the first method the turning after each impact/shock or press is not necessary. It is possible to deform one side of blank, supplying it along the axis/axle and after this to make turning. Reduction ϵ must be less than the value, with which the conversion factor φ exceeds 2-2.5 and the formation of the clamps (see Fig. 2f) is possible. For example, during forging of ingots under the presses the absolute value of reduction $\Delta h \leq 150$ mm. The value of reduction on the latter/last squeezing must be more or less than the critical degree of the deformation of the machined alloy at this temperature for warning/preventing grain-growth. supply for obtaining the smooth surface must be less than the difference b-Δl* virtually l=(0.4-0.75) of b (where b - width of face according to Tables 2).

For obtaining the forging of round cross section blank they first extract to the square, whose section/cut is somewhat larger than the required round cross section. Then by squeezing along the diagonal (Fig. 2g) are dulled angles and they roll the obtained octahedron on the average. Final upsetting is produced in the swages/snaps or the notched strikers. Such faces are very effective for the churning of corners of a square (Fig. 2h).

Selection of press and hammer. Press for the drawing of this blank it is possible to select according to Table 3, and the required effort/force it to determine according to the formula

$$P = \gamma m \sigma_{e} a l,$$

where γ - coefficient, which considers the effect of the diagram of deformation. For the drawing in the platens γ=1, and in the carved γ=1.25;

$$m = 1 + \frac{3c - e}{6c} \mu \frac{l}{h};$$

if a>l, then c=a and e=l, if a<l then c=l and e=a; here a - width or the diameter of blank, l - supply.

2. Tentative width of faces of swages and hydraulic presses.

(1) Вес падающих частей в кГ	(2) Ширина бойка молота в мм		(5) Усилие пресса в т	(6) Ширина бойка в мм
	(3) пневматического	(4) паровоздушного		
100	70—80	—	600	180—200
150	80—95		800	220—260
200	95—110		1000	260—300
300	100—125		1200	280—320
400	110—130		1600	320—360
500	120—150	140—230	2000	360—420
750	130—160	150—250	2500	400—480
1000	140—175	150—280	3000	450—520
1500	160—200	200—300	4000	500—600
2000	—	200—350	5000	550—700
2500		220—350	6000	600—750
3000		280—400	8000	700—850
4000			10000	800—950
5000		330—400		

Key: (1). Weight of the falling/incident parts in the kgf. (2). Width of face of hammer in mm. (3). pneumatic. (4). steam-air. (5). Effort/force of press in t. (6). Width of face in mm.

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For determining the effort/force it is possible to take the initial values of a, h and l.

Example. To select press for the drawing in the platens of blank of the alloy AK6 with the sizes/dimensions of $a_0=h_0=1000$ mm. Blank is maximum for the press 1200 t and is minimum for the press 3000 t (see Table 2). Average/mean value corresponds to press in 2000 t.

Testing. We accept the temperature of forging 400°C; then $\sigma_{s,400}$= 6 kg/mm², μ=0.5; the width of face for the press 2000 t b=420 mm (see Table 2), l=0.75 b=0.75·420=315 mm.

With the given a_0 and l we obtain $c=a_0$=1000; $e=l$=315;

$$m = 1 + \frac{3c - e}{6c}\mu\frac{e}{h} =$$
$$= 1 + \frac{3 \cdot 1000 - 315}{6 \cdot 1000} \cdot 0{,}5\,\frac{315}{1000} = 1{,}07;$$
$$P = m\sigma_s a_0 l = 1{,}07 \cdot 6 \cdot 1000 \cdot 315 =$$
$$= 2\,022\,300 \text{ kgf},$$

whence P=2022 t.

Consequently, press 2000 t is acceptable for accomplishing this operation.

Hammer for the drawing it is possible to select according to Table 4, and required effort/force it to determine and to test by calculation, on the basis of designation/purpose or evaluation of the degree of deformation, obtained for one impact/shock, according to the formula

$$\eta_y L_M = A_\phi.$$

To work of deformation for one impact/shock

$$A_0 = \omega\gamma m\sigma_s\varepsilon Fl.$$

For obtaining A in the kgfm one should substitute σ_s in kg/mm²; F in cm²; l in cm.

Example. To select steam-air swage for the drawing in the platens of blank of the alloy AK6 with the sizes/dimensions of $a_0=h_0=200$ mm. Blank is maximum for the hammer 750 kgf and is minimum for the hammer 5000 kgf and is minimum for the hammer 5000 kgf (table 4). Average/mean value corresponds to hammer 2000 kgf.

Testing. We accept the temperature of forging 400°C; kg/mm², $\omega=3$; $\gamma=1$; $\mu=0.5$; the width of face for the hammer 2000 kgf (table 2) b=250 mm; $l=0.4$ b=0.4·250=100 mm.

With given a_0 and l we obtain $c=a_0=200$ mm; $e=l=100$ mm;

$$m = 1 + \frac{3c-e}{6c}\mu\frac{e}{h} = 1 + \frac{3\cdot 200 - 100}{6\cdot 200}\cdot 0{,}5\cdot\frac{100}{200} = 1{,}09;$$

$$F_0 = 20\cdot 20 = 400 \text{ см}^2;$$

$$A = 3\cdot 1\cdot 1{,}09\cdot 6\cdot 400\cdot 10\varepsilon = 75\,000\varepsilon.$$

We accept $\eta_y = 0{,}8$; $L_м = 2{,}15\,G$.

Then for two-ton hammer $L_м = 4300$ kgfm; $\eta_y L_м = 75\,000\,\varepsilon$; 0.8·4300=75000 ε, whence ε=0.8·4300/7500=0.046.

3. Dependence of the effort/force of press on the diameter of blank.

(1) Усилие пресса в Т	(2) Диаметр исходной заготовки в мм		(1) Усилие пресса в Т	(2) Диаметр исходной заготовки в мм	
	(3) макси-мальный	(4) мини-мальный		(3) макси-мальный	(4) мини-мальный
500	200	550	3 000	1000	1600
800	300	800	4 000	1200	1900
1 000	400	900	6 000	1400	2100
1 200	500	1000	6 000	1600	2300
1 500	600	1150	8 000	1900	2600
2 000	700	1300	10 000	2100	2800
2 600	850	1500			

Key: (1). Effort/force of press in t. (2). Diameter of initial blank in mm. (3). maximum. (4). minimum.

4. Weight of falling/incident parts of swage for drawing.

(1) Вес падающих частей в т	(2) Сторона квадрата или диаметр исходной заготовки в мм		
	(3) мин.	(4) сред.	(5) макс.
(6) Для пневматических молотов			
100	30	—	90
150	40	—	110
200	50	—	120
300	65	—	140
400	75	—	160
600	80	—	180
(7) Для паровоздушных молотов			
500	80	120	180
750	95	140	200
1000	110	150	230
1500	125	180	260
2000	140	200	280
2500	150	215	310
3000	165	230	330
4000	180	250	370
6000	200	275	400

Key: (1). Weight of the falling/incident parts in t. (2). Side of square or diameter of initial blank in mm. (3). min. (4). media. (5). max. (6). For pneumatic hammers. (7). For steam-air hammers.

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This degree of deformation for the first squeezing is satisfactory.

Basic operations. Flattening. Each press or impact/shock with the flattening must provide the greatest broadening with smallest elongation. It is expedient to produce this operation with wide platen with the greatest supply l.

Distribution on the mount/mandrel (Fig. 3). Forging is conducted with the rotary supply of blank. The long side of face is paralle. to the axis/axle of forging. Reduction

$$l = \frac{F_з}{F_к} = \frac{\delta_0 l_0}{\delta_к l_к} = \frac{D_{кср}}{D_{оср}}.$$

Auxiliary operations. Drawing out of tail (Fig. 4a) is applied mainly during forging of ingot from the side of riser. The length of it is approximately/exemplarily 2 times more than diameter.

Rough draft - plotting on the surface of the blank of marking deepenings (Fig. 4b) is accomplished/realized by fullers of small diameter.

Narrowing - increase of marking deepenings before necking of he

specific thickness is accomplished/realized, depending on the required profile/airfoil by different unrollings, fullerings (Fig. 4c, d, e).

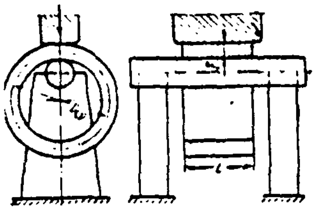

Fig. 3. Diagram of unrolling ring on the mount/mandrel.

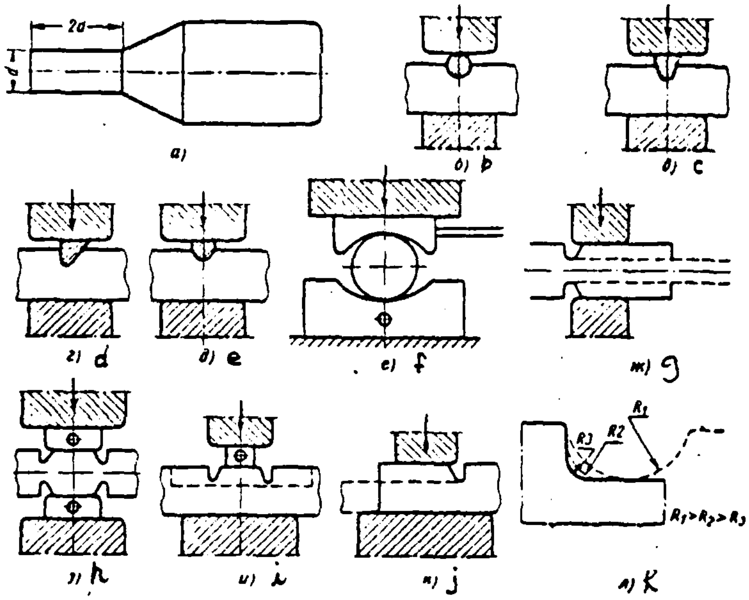

Fig. 4. Diagram of auxiliary operations during forging.

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The narrowing of round blank should be made in the semicircular swage/snap (Fig. 4f), gradually turning the blank around the axis/axle.

The formation of steps in indentations is accomplished/realized in the following sequence: rough draft, narrowing at the depth of step or indentation, drawing of step or indentation. If the length of the section of the blank, where is made step or indentation, is considerable, then drawing is produced directly with faces (Fig. 4g). At the low length of section they preliminarily conduct drawing with the use/application of flat/plane or oval unrollings (Fig. 4h). If step either indentation one-sided, then to avoid squeezes from smooth side drawing is made by unrollings (Fig. 4i) or by faces established/installed crosswise (Fig. 4j).

In order not to intersect filament in the zone of the formation of projection, unrollings with the gradually decreased radius (Fig. k) are applied.

Planishing either smoothing along the length is made for eliminating the inequalities after drawing by tap of hammer or by the presses of press. Supply is designated the greatest for the faces l=b used.

PIERCING.

Piercing without lining ring is applied for the formation of through and blind openings in the forgings (Fig. 5a, b, c). With this

method of piercing the distortion of the form of blank (decrease of its height/altitude, an increase in the diameter, the appearance of barrel-shape form, and also convexity on one end/face and concavity on other (Fig. 5d and e) occurs. Ratio H/h_0 can be determined according to Table 5, and the greatest diameter of blank after piercing according to the formula

$$D_{max} = 1{,}13 \times \sqrt{\frac{1{,}5}{H}\left[V + f(H - h) - 0{,}5F_0\right]},$$

where V - volume of blank in mm^3; f - cross-sectional area of punch in mm^2; F_0 - cross-sectional area of blank in mm^2; H and h - in mm (Fig. 5).

The effort/force, required for the piercing, is determined f[illegible] the formula

$$P = m\sigma_e f,$$

where

$$m = \left(1 + \frac{\mu}{3} \cdot \frac{d}{h}\right)\left(1 + 1{,}15 \ln \frac{D}{d}\right).$$

Piercing and backing rings is made for the formation of openings in the blanks of small height/altitude (Fig. 5f and g). In this case waste (metal scrap) formable in this case is more than with the piercing without the backing ring, but the distortion of form is less.

The formation of openings with a diameter of >400 mm in the ingots is predominantly accomplished/realized by hollow broaches.

Ratio H/h_0 depending on ratio d/D_0 and h/h_0.

<table>
<tr><th rowspan="2">$\frac{d}{D_0}$</th><th colspan="5">(1) H/h_0 при h/h_0</th></tr>
<tr><th>0,15</th><th>0,2</th><th>0,3</th><th>0,4</th><th>0,5</th></tr>
<tr><td>0.2</td><td colspan="2">0.90</td><td>0.92</td><td>0.93</td><td>0.94</td></tr>
<tr><td>0.4</td><td colspan="2">0.85</td><td>0.86</td><td>0.88</td><td>0.90</td></tr>
<tr><td>0.5</td><td colspan="2">0.80</td><td>0.82</td><td>0.83</td><td>0.85</td></tr>
<tr><td>0.6</td><td colspan="2">0.72</td><td>0.74</td><td>0.76</td><td>0.80</td></tr>
<tr><td>0.7</td><td colspan="2">0.64</td><td>0.66</td><td>0.70</td><td>0.78</td></tr>
<tr><td>0.8</td><td colspan="2">0.53</td><td>0.58</td><td>0.63</td><td>0.66</td></tr>
</table>

Key: (1). with.

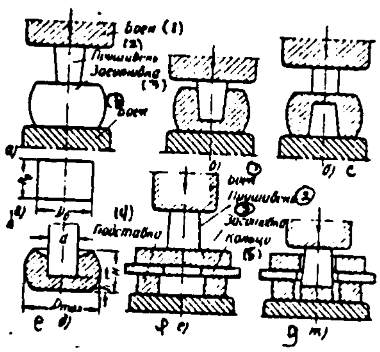

Fig. 5. Diagram of piercing.

Key: (1). Face. (2). Broach. (3). Blank. (4). Support/socket. (5). Ring.

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In this case the center of ingot is removed, what is great advantage.

CUTTING.

Are applied two methods of cutting the blanks: cutting on one side (Fig. 6a, b, c) and cutting from two sides (Fig. 6d, e, f).

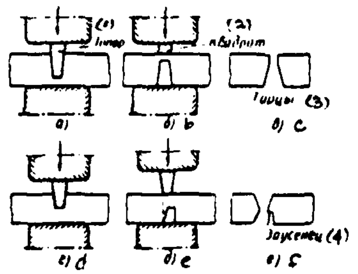


Fig. 6. Diagram of cutting.

Key: (1). Axe. (2). Square. (3). Ends/faces. (4). Projecting edge.

BENDING.

Bending is accompanied by the distortion of the initial form of the cross section of blank and by the decrease of its area in the zone of bending (Fig. 7). A radius in the inflection point of blank must not be less than one-and-a-half thicknesses of its section/cut. The thickening (Fig. 7b) is made for preventing the decrease of section/cut in the zone of bending on the blank in the necessary place.

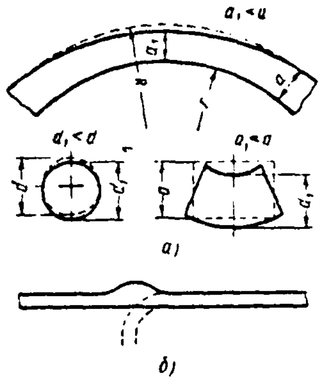


Fig. 7. Diagram of the distortion of the initial form of blank during the bending.

COMPILATION OF THE DRAWING OF FORGED BLANK.

Source document for developing the drawing of forging is the drawing of the clean/finishing part, whose contours/outlines will be applied to the drawing of forging by conditional dotted line.

The machining allowances and the tolerances in size are determined according to Table 6 depending on the length of part, form and sizes/dimensions of its section/cut. Under each size/dimension of forging, in the brackets, they enter/write the appropriate size/dimension of clean/finishing part. If chopping is the latter/last operation of the technological process of forging, then the ends/faces of forging are left chamfered (see drawing/draft in Table 6). The rake angle must not exceed 10°. If forging has

rectangular cross section, then allowances and tolerances designate according to the maximum size of section/cut.

In the drawings to the forgings for the parts of critical/heavy-duty designation/purpose they usually indicate the necessary fiber direction, which must be provided with technological process.

In the drawings to the forgings for the especially critical parts sometimes is provided for the special extra thickness, from which are cut out the samples/specimens for the mechanical tests and the metallographic examinations. Forgings can have the special extra thicknesses, provided for by the technological process of the subsequent machining. In all cases the form and the sizes/dimensions of extra thicknesses must be matched with the appropriate specialists.

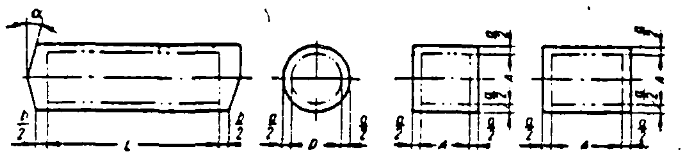
DEVELOPMENT OF THE TECHNOLOGICAL PROCESSES OF FORGING.

The technological processes of forging blanks of the alloys of nonferrous metals in the part of the selection of initial blanks, balance of metal, content and sequence of operations and shaping virtually in no way differ from the technological processes of forging steel blanks. Exceptions are the losses of metal to the

carbon monoxide, which during forging of the alloys of nonferrous metals are not considered, the thermomechanical modes/conditions of deformation and heating devices.

For a trouble-free operation of forging aggregate/unit the latter must be serviced by two heating installations, of which the blanks overhang consecutively/serially. The values of charges/shrinkages must be connected with the heating time and the rhythm of work, thus, in such a way that the heating devices would not limit forging aggregate/unit.

6. Machining allowances and tolerances in size of forged blanks, manufactured on hammers and presses.



(1) Длина детали L в мм	(2) Размеры детали, на которые назначаются припуски и допуски	(3) Припуски a и b и отклонения при диаметре D, или размеры сечения A и B в мм					
		25—50	50—80	80—120	120—180	180—280	200—360
До 250	D, A, B L	4 ± 1,5 12 ± 5	5 ± 2 15 ± 5	6 ± 3 20 ± 7	—	—	—
250—500	D, A, B L	5 ± 2 15 ± 5	6 ± 2 20 ± 6	7 ± 3 23 ± 8	8 ± 3 26 ± 8	12 ± 4 32 ± 10	14 ± 4 36 ± 10
500—800	D, A, B L	6 ± 2 18 ± 5	8 ± 2 22 ± 7	9 ± 3 25 ± 8	11 ± 3 30 ± 10	12 ± 4 35 ± 10	13 ± 4 49 ± 12
800—1250	D, A, B L	7 ± 2 22 ± 0	9 ± 3 26 ± 8	11 ± 3 30 ± 10	12 ± 4 35 ± 10	14 ± 4 40 ± 12	15 ± 5 45 ± 12
1250—2000	D, A, B L	8 ± 2 26 ± 8	10 ± 3 30 ± 8	12 ± 4 36 ± 10	13 ± 4 36 ± 10	15 ± 5 45 ± 12	16 ± 5 45 ± 12
2000—2500	D, A, B L	10 ± 3 30 ± 8	12 ± 3 33 ± 8	14 ± 4 38 ± 10	16 ± 5 45 ± 12	17 ± 5 45 ± 12	—

Key: (1). Length of part L in mm. (2). Sizes/dimensions of part, to which are designated allowances and tolerances. (3). Allowances a and b deviation with diameter D, or sizes/dimensions of section/cut A and B in mm.

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Chapter 4.

ELEMENTS OF CONSTRUCTION OF STAMPINGS AND TOOLS, POWER OF MACHINES.

Open-die forging.

During planning of parts from the alloys of the nonferrous metals, manufactured from the stamped/die-forged blanks, it is necessary to consider: technological special features/peculiarities and physical properties of material and possibility of manufacturing the part with the minimum expenditures of metal and labor/work; the specific special features/peculiarities of hot die forging, i.e., to indicate drafts the non-machined surfaces, which do not lie at the parting plane; to designate necessary radii of couplings, transition and curvature; it is correct to select the relationships/ratios between thickness and width of fabric, height/altitude and thickness of edge/fin.

The parts, manufactured from the stamped/die-forged blanks, must

have smooth transitions from one section/cut to another. It is especially important so that the parts would not have the large difference of the cross-sectional areas, arranged/located on the small of distance from each other.

Pretreatments are accomplished/realized mainly by free ductile which it is labor-consuming and it does not provide the distribution of material with the necessary precision/accuracy. The increased consumption of metal is observed in connection with this during stamping of blanks for the parts with the large difference in the sections/cuts. The large volume of the metal, extruded from the cavity, leads to the rapid wear of dies/stamps, and the nonuniform distribution of flash along the contour/outline of part causes nonuniform stresses and strains of die/stamp, misalignment and displacement, the leading to the distortion forms of the blank to be stamped.

Elements of the construction/design of stampings.

During the development of the drawing of stamping it is necessary to select the joint of die/stamp, to establish/install the optimum relationships/ratios of structural elements/cells, to mark machining allowances and tolerances in size, to select drafts.

Joint of die/stamp. During the selection of the die line it is necessary to be guided by the following general considerations:

it is desirable so that the parting line would lie/rest at one plane or maximally this would approach. In this case the equipment is characterized by simplicity and low cost/value, the process of stamping proceeds more easily and with a smaller quantity of waste/reject, than during the stamping with the joint over the broken line;

blanks with the broken parting line should be furnished in the die/stamp so that its sections would be sloped and horizontal pla at angle not exceeding 60° (Fig. 1a). This arrangement of parting line improves the conditions for stamping and trimming flash;

in the stampings with the bilateral projections, the edges/fins or the indentations parting line should be marked out on the middle of the lateral surface of the greatest perimeter of part (Fig. 1b, c). This facilitates the control of the possible displacement of one half of stamping relative to another;

in stampings of box-shaped form and similar to them - parting line must pass through the apexes/vertexes of walls (Fig. 1d, e, f, g).

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In this case is obtained such fiber direction, in which the stampings possess the best mechanical properties and in their walls are not formed clamps, leakages and other defects/flaws;

during the selection of parting line it is necessary to approach the arrangement of stamping in one face of die/stamp (Fig. 1,h, i). This considerably decreases the cost/value of the latter and raises the precision/accuracy of stamping;

in the general cases it is desirable so that the parting line would pass on the greatest perimeter of stamping. In this case the depth of the die cavities minimum, thanks to which is facilitated their filling and is reached optimum productivity; the value of allowance for the creation of draft is decreased, thanks to which the consumption of metal descends and the labor consumption for subsequent machining.

The thickness of fabric is the basic structural element of the stamped/die-forged blank both from the point of view of effect to the weight characteristics of part without the machining of fabric and

from the point of view of the complexity of obtaining the fabric of small thickness by the methods of hot die forging.

The possibility of obtaining the fabric of minimum thickness is determined by the resistance of metal to deformation, by rate of cooling of blank in the process of stamping, by temperature of deformation and by corrosive properties of metal.

According to the data of E. P. Unkson the average/mean specific resistance to the deformation: with free upsetting of the round blanks

$$q = \sigma_T\left(1 + 0,17\frac{d}{h}\right);$$

with upsetting without the broadening of the rectangular blanks

$$q = \sigma_T\left(1 + 0,25\frac{a}{h}\right),$$

where σ_T - yield point at deformation temperature; d - diameter of blank after upsetting; a) the smaller side of rectangle; h) the thickness of the upset blank.

From these formulas it follows that the specific resistance to deformation grows/rises due to an increase in the yield point in connection with cooling of blank and due to a change in the form, i.e., increase in ratio D/H or a/h.

According to the same data the true resistance to deformation, 2-3 times the exceeding average, is determined from the formula

$$\sigma_y = \sigma_T e^{\frac{2\mu}{h}\left(\frac{a}{2} - x\right)},$$

where x - distance from the center of sample/specimen, to the point where is determined stress/voltage, or according to the simpler formula, which is obtained from preceding/previous by decomposition in the series/row and simplification,

$$\sigma_y = \sigma_T\left[1 + \frac{2\mu}{h}\left(\frac{a}{2} - x\right)\right].$$

Maximum stress/voltage (in the center of fabric with x=0)

$$\sigma_y^{max} = \sigma_T\left(1 + \frac{\mu a}{h}\right).$$

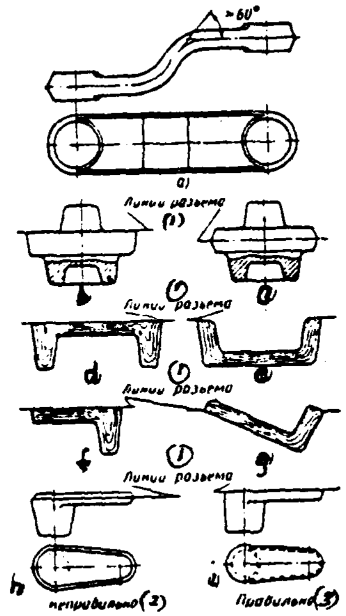

Fig. 1. Parting lines in the blanks.

Key: (1). Parting lines. (2). incorrect. (3). correct.

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Accepting μ=0.5 for the case, when shearing stresses τ attain the maximum value, caused by the equation of plasticity, we will obtain

$$\sigma_y^{max} = \sigma_T\left(1 + 0,5\,\frac{a}{h}\right).$$

Minimum stress/voltage (from the edge of fabric with x=a/2)

$$\sigma_y^{min} = \sigma_T.$$

Thus, with an increase in ratio a/h is raised not only average/mean specific resistance, but also voltage difference between middle and edge of fabric, which, in turn, increases a difference in elastic deformations $(w_{max} - w_{min})$ in the appropriate places of die/stamp (Fig. 2). The amount of elastic deformations according to the formula of Boussinesq is equal to

$$w = \frac{P(1-\lambda^2)}{\pi E s},$$

where P - external forces, which cause deformation; λ - Poisson ratio; E - modulus of elasticity; s - distance from the point of application of force to the point, at which is determined elastic deformation.

A difference in elastic deformations in different places for the die cavity leads respectively to different thicknesses of fabric - greatest in the middle and smallest on the edges (the so-called lenticular form). Consequently, the maximum thickness of the fabric, obtained by hot die forging, is the thickness, for obtaining by which the necessary specific pressure does not exceed elastic limit of steel, from which are made the dies/stamps. Furthermore, the thickness of not undergoing subsequent machining fabrics is regulated

by a difference in the thicknesses in the center and in the edges.

Taking into account an increase of the thickness of fabric as a result of the wear of dies/stamps, which depends in essence on the resistance to deformation, and change in the measure of contraction as a result of the instability of the thermal mode of stamping, the elastic deflection of dies/stamps must not exceed certain part of half of the permissible positive deviation of the thickness of fabric (keeping in mind thickening fabric into both sides due to elastic deformations, wear, etc. of the upper and lower dies of die/stamp), i.e.

$$w_{max} - w_{min} \leq \xi \frac{\Delta h}{2},$$

where ξ - coefficient, which considers, what part of half of the permissible positive deviation can be used for the distortion of the form of fabric (lenticularity) from elastic deformation of face (for the aluminum, magnesium and copper alloys ξ=0.6; for the the titanium ξ=0.5); Δh - permissible positive deviation of the thickness of fabric in mm.

In the formula are not considered elastic deformations of the material to be stamped, which can be disregarded/neglected in view of the high plasticity of metal during the hot deformation.

If the value of elastic deflection proves to be more than $w_{max} - w_{min}$, first this indicates which to obtain the required thickness of fabric by stamping is inexpedient and it should be increased. This decreases the elastic deflection and the wear of dies/stamps as a result of the resistance to deformation. The final dimension of fabric is obtained by machining.

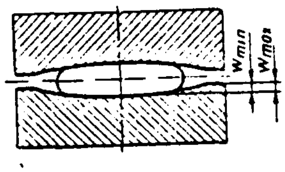

Fig. 2. Diagram of elastic deformation of die/stamp.

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In certain cases the minimum thickness of fabric is determined not technical capabilities of its obtaining by the methods of hot die forging, but by physical properties of material. Thus, for instance, in magnesium alloys the minimum thicknesses of structural elements/cells are determined by corrosion resistance.

In the determination of the thickness of fabric physical and shop characteristics, ratio of the width of fabric to the thickness, area of fabric and ratio of its length to the width have vital importance. The greater the area of fabric other conditions being equal the more must be the thickness of fabric, while the greater the ratio of length to the width of fabric, the fact the thickness of fabric can be less.

The blanks, which consist of one thin fabric, barely are

encountered in the practice of hot die forging. Usually it is the element of the construction/design of part. In combination with the edges/fins the fabric forms the open (Fig. 3a) and closed (Fig. 3b) sections/cuts, whose form exerts a substantial influence on the thickness of fabric. In the open section/cut the width of fabric (Fig. 3c) is decreased from the presence of edge/fin and is actually equal to $a_1 = a - a_2$, and $a_1/s < a/s$ in the flat/plane section/cut of the same width.

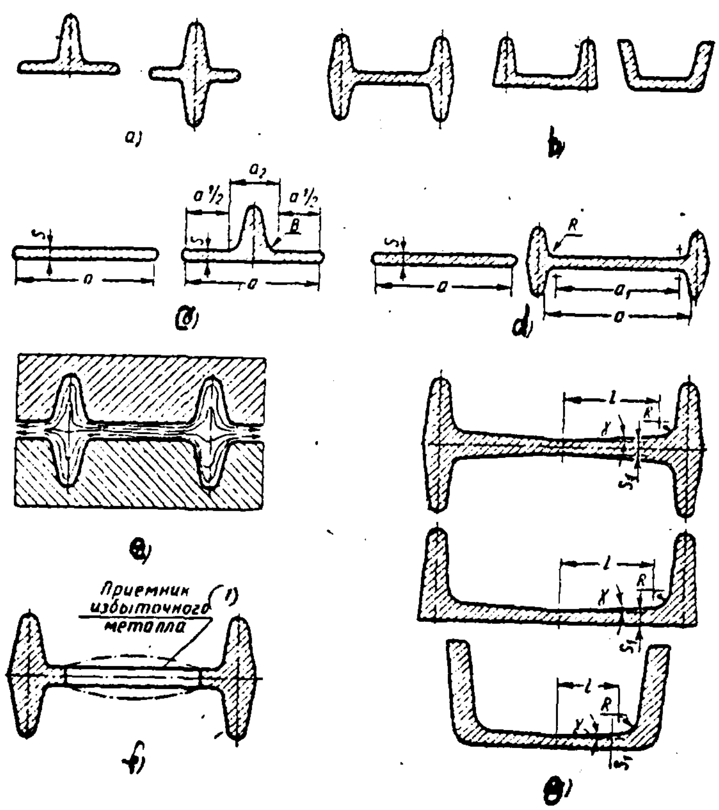

Fig. 3. Form of lines of blanks with thin fabric.

Key: (1). Receiver of excessive metal.

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Furthermore, the edge/fin of the open section/cut contributes to the retention/preservation/maintaining heat in the fabric and thereby it improves stamping conditions. Consequently other conditions being equal the thickness of the fabric of the open section/cut can be less than flat/plane one.

In the closed section/cut width a_1 (Fig. 3d) fabric also is decreased from the presence of edges/fins, but the conditions for the formation of thin fabric here are considerably more complicated than in the open section/cut. The edges/fins arranged/located along the edges impede the displacement of excessive metal from the fabric in the flash (Fig. 3e). Therefore it is possible to consider with a sufficient degree of accuracy that the conditions for the formation of thin fabric in the flat/plane and closed sections/cuts are analogous.

Lightening hole on the fabric of the closed section/cut is utilized as the additional receiver of excessive metal (Fig. of

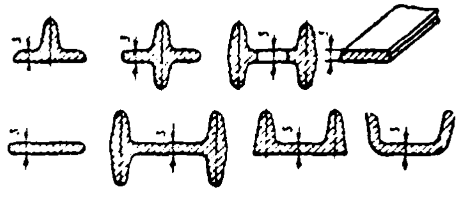
echis) and it actually decreases the width of fabric. It is possible to consider in this case that the conditions for the formation of thin fabric in the closed and open sections/cuts are identical.

For the effective use of a lightening hole as the receiver of excessive metal its area must comprise not less than 50% area of thin fabric.

1. Thickness of fabrics v for different sections/cuts.

1-я группа сечений (1)

2-я группа сечений (1)



(2) Площадь проекции штампованной заготовки на плоскость разъема в см²	(3) Сплавы											
	(4) Алюминиевые и медные		(5) Магниевые								(6) Титановые	
			МА2		ВМ65-1		МА3		МА5			
	Группы сечений (7)											
	1	2	1	2	1	2	1	2	1	2	1	2
	s в мм											
(5) До 25	1,5	2,0	1,5	2,0	1,5	2,0	4,0	4,0	7,0	7,0	1,5	2,0
Св 25 до (8) 80	2,0	2,5	2,0	2,5	2,5	3,0	4,5	4,5	7,5	7,5	2,5	3,0
(9) » 80 » 100	2,5	3,0	2,5	3,0	3,5	4,0					3,5	4,0
» 100 » 250	3,0	3,5	3,0	3,5	4,0	5,0		5,0			4,5	5,0
» 250 » 500	4,0	4,5	4,0	4,5	5,0	6,0	5,0	6,0			5,0	6,0
» 500 » 850	5,0	5,5	5,0	5,5	6,0	8,0	6,0	8,0		8,0	6,0	8,0
» 850 » 1 180	5,5	6,5	5,5	6,5	7,5	10,0	8,0	10,0	8,0	10,0	8,0	10,0
» 1 180 » 2 000	7,0	8,0	7,0	8,0	9,0	12,0	10,0	12,0	10,0	12,0	10,0	12,0
» 2 000 » 3 150	8,0	9,0	8,0	9,0								
» 3 150 » 4 500	9,0	10,5	9,0	10,5								
» 4 500 » 6 300	10,5	12,0	10,5	12,0								
» 6 300 » 8 000	11,5	13,0	11,5	13,0								
» 8 000 » 10 000	12,5	14,0	12,5	14,0								
» 10 000 » 12 500	13,5	15,0	13,5	15,0								
» 12 500 » 16 000	15,0	16,5	15,0	16,5								
» 16 000 » 20 000	16,5	18,0	16,5	18,0								
» 20 000 » 25 000	18,0	20,0	18,0	20,0								

Key: (1). the 1st group of sections/cuts. (2). Projected area of stamped/die-forged blank on parting plane in cm². (3). Alloys. (4). Aluminum and copper. (5). Magnesium. (6). Titanium. (7). Groups of sections/cuts. (8). To. (9). SV.

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Table 1 gives the values of the thicknesses of fabrics depending on the area of stampings for various forms of sections/cuts.

For facilitating the metal flow in the closed sections/cuts with the large distance between the edges/fins of fabric they sometimes make by those thickening from the middle towards edges/fins (Fig. 3h). In this case the thickness of fabric in the middle part of the section/cut is determined from the formulas: for the double-T sections/cuts

$$s_1 = s - (L + R)\,\mathrm{tg}\,\gamma;$$

for the channel sections/cuts

$$s_1 = s - \frac{1}{2}(L + R)\,\mathrm{tg}\,\gamma,$$

where s - thickness of fabric, determined according to tables 1; γ - angle of the slope of fabric, determined according to tables 2; L and R - sizes/dimensions, usually indicated on the drawing.

Drafts on the surfaces of stampings, perpendicular to the parting plane, are necessary for the removal/distance of blank of the die cavity. Are distinguished drafts: the external α, furnished along the outer duct parts, and internal β, that are furnished along the contour/outline of indentations.

Small drafts cause the formation of the undercuts in the cavity of die (Fig. 4), which are the result of the large stresses/voltages, which appear in the zone of barb bridge from the deformation of the metal ensuing/escaping/flowing out in the flash.

Forming undercut causes sticking blank in the die/stamp.

The value of internal drafts depends on configuration and material of the blank to be stamped, and also on the equipment used and the instrument (presence of knock-outs die).

The value of effort/force P, necessary for the removal/distance of blank of the cavity of die (effort/force of knockout), is characterized by the formula

$$P = \Sigma F\sigma(\mu - \mathrm{tg}\,\beta),$$

where F - lateral surface of indentation in the stamping, which encompasses its projection; σ - stresses/voltages on the contact surface of stamping and projection of die/stamp, which appear as a result of shrinkage; μ - coefficient of the friction of the metal being deformed against the die/stamp at a temperature of knockout; β - internal draft; Σ - sign, which indicates that if the stamping has several deepenings, then their lateral surfaces are totaled.

As this follows from the given formula P=0, when

$$\mu = \operatorname{tg} \beta.$$

In the specific cases, when configuration, overall dimensions and material of stamping are known, the values of drafts depend on the form of section/cut and relation of height/altitude h of part, or element/cell of part, to which is given the stamping draft/gradient, to width b (Fig. 5).

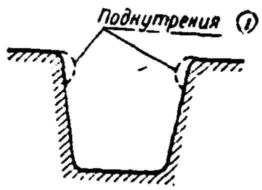

Fig. 4.

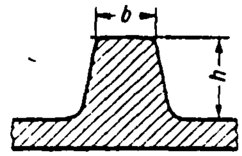

Fig. 5.

Fig. 4. Diagram of formation of undercuts in die cavities.

Key: (1). Undercuts.

Fig. 5. Element/cell of part, to which is given draft.

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In the carrying out of stampings in th dies/stamps with the knockouts such drafts/gradients must be selected, that the stresses/voltages appearing with the knockout would not cause warping/buckling (deformation) the stamped blanks.

Virtually it is not always expedient to designate different drafts on the external and internal surfaces of stampings. Thus, for instance, different drafts in the double-T and channel sections/cuts

complicate sinking die. Different drafts on the external and internal surfaces can be applied for stampings or elements of the stampings, which have the shape of the bodies of revolution, for which the die cavity is worked on the turning boring machine, but not by milling.

Most widely used for the alloys of the nonferrous ~~ones~~ metals are forging inclines at 3-7°.

If different drafts are obtained at the separate places of stamping, then must be unitized them, after making different drafts/gradients only in the places, which do not cause difficulty during sinking of dies.

It is expedient to make the external drafts/gradients of stampings of high altitude, which have the shape of bodies of revolution, by variables (Fig. 6). In this case draft, which comes out on the parting line, is made with the equal to 7° at depth ∾ of 15-20 mm, and with larger depth of -1.5-2°. This gives perceptible metal savings and somewhat decreases the volume of subsequent machining. The optimum values of drafts are given in Table 2.

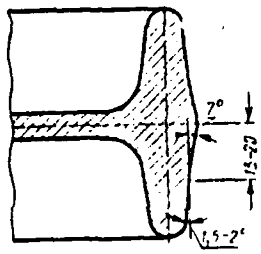
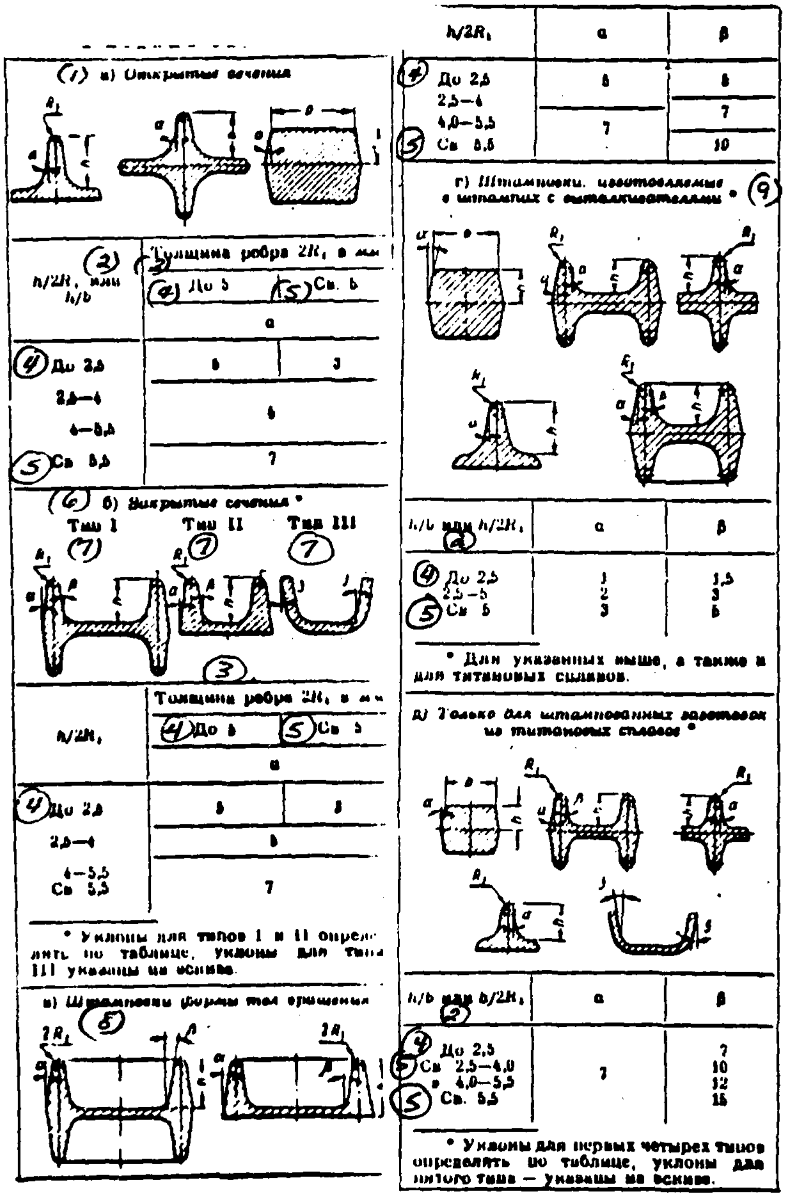


Fig. 6

Diagram of variable forging incline.

2. Drafts α (external) and β (internal) in deg. For the blanks of the aluminum, magnesium and copper alloys.



Key: (1). a) the open sections/cuts. (2). or. (3). Thickness of edge/fin $2R_1$, in mm. (4). To. (5). SV. (6). b) closed sections/cuts.

FOOTNOTE [1]. Drafts/gradients for types I and II to determine according to table, drafts/gradients for type III are indicated on the drawing/draft. ENDFOOTNOTE.

(7). Type. (8). c) stampings of shape of bodies of revolution. (9). d) stampings, manufactured in dies with knockouts[1].

FOOTNOTE [1]. For those indicated above, and also for titanium alloys. ENDFOOTNOTE.

(10). e) only for stamped blanks of titanium alloys[1].

FOOTNOTE [1]. Drafts/gradients for the first four types to determine according to table, drafts/gradients for fifth type - are indicated on the drawing/draft. ENDFOOTNOTE.

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Thickness of edges/fins, the radii of transitions, bending and couplings, the angles of the slope of fabric. The extrusion of metal in the cavity of the dies, which form edges/fins on the stamped/die-forged blanks, occurs due to the stresses/voltages, which appear due to the stresses/voltages, which appear in the volume being

deformed as a result of limiting the metal flow to the sides by the bridge of barb groove, and also by the action of the forces of external friction, which prevent the displacement/movement of metal over the contact surface of die/stamp and its displacement in the flash.

The value of specific pressure q, necessary for the displacement of metal into the conical cavity, can be determined according to Ye. P. Unksov's formula

$$q = \sigma_T \frac{1}{\alpha} \ln \frac{F_0}{f},$$

where σ_T - yield stress of metal at deformation temperature; α - apex angle of conical cavity in rad; f - smallest cross-sectional area of cavity; F_0 - greatest cross-sectional area of cavity.

If we instead of the conic section examine trapezoidal, then the area ratio it is possible to replace with the appropriate relation of the thicknesses of edge/fin in base/root b_0 and at apex/vertex b and formula will take the form

$$q = \sigma_s \frac{1}{\alpha} \ln \frac{b_0}{b}.$$

Change α in this formula is examined only at constant values of b_0 and b, in this case an increase α leads to the decrease of the

depth of cavity, which facilitates its filling and, on the contrary, decrease α increases the depth of cavity and thereby impedes its filling, i.e., raises required specific pressure.

As follows from the given formula, stress/voltage, necessary for the extrusion of metal into the inswept cavity, it grows/rises with increase σ_T, i.e. during cooling of blank, and also with increase in b_0 and decrease b.

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Ratio $b_0/b>1$, i.e., in the die cavity always must be draft. e nearer this relation to 1, i.e., the less draft, the less the specific pressure, necessary for the filling of the inswept cavity. When draft is absent, $b_0/b=1$ specific pressure q=0. This means that with the extrusion of metal into the cavity with the vertical walls the deformations of metal, included in this cavity, does not occur, pressure is here expended/consumed only on the extrusion of metal, i.e., overcoming friction between the metal and the vertical walls.

The pattern of the flow of metal with the filling of edges/fins in stampings from the aluminum and magnesium alloys differs significantly from stampings from copper and titanium alloys.

The flow pattern is determined by the relationship/ratio of the temperatures of the beginning of deformation and preheating of dies/stamps. The temperature of the surface of the die cavity at the moment of deformation is determined from the formula

$$T = \frac{t_n + t_w}{2},$$

where t_n – temperature of the beginning of deformation; t_w – temperature of preheating dies/stamps.

The nearer t_n and t_w, the less the temperature differential between the surface of the blank being deformed and its middle, the more plastic the metal on the contact surface and the better its displacement/movement in the process of filling of cavity occurs.

Fig. 7a shows filling of cavity during the deformation of titanium alloys, while in Fig. 7b - aluminum alloys.

With the filling of the edges/fins of the open sections/cuts excessive metal arranged/located on both sides of edge/fin is fixed into the edge/fin (Fig. 7c). With the filling of the edges/fins of the closed double-T sections/cuts the intense metal flow through the edges/fins occurs, since excessive metal is extruded in the flash, as shown in Fig. 3e.

If in the open sections/cuts the thickness of edge/fin, other conditions being equal, depends only on the height/altitude of edge/fin, then in the closed double-T sections/cuts under the same conditions the thickness of edge/fin depends on the height/altitude of edge/fin and distance between the edges/fins, since this distance determines a quantity of metal flowed/occurred/lasted through the edges/fins by itself.

It is customary to assume that in practice the thickness of edge/fin must be 6.5-10 times of less than its height/altitude.

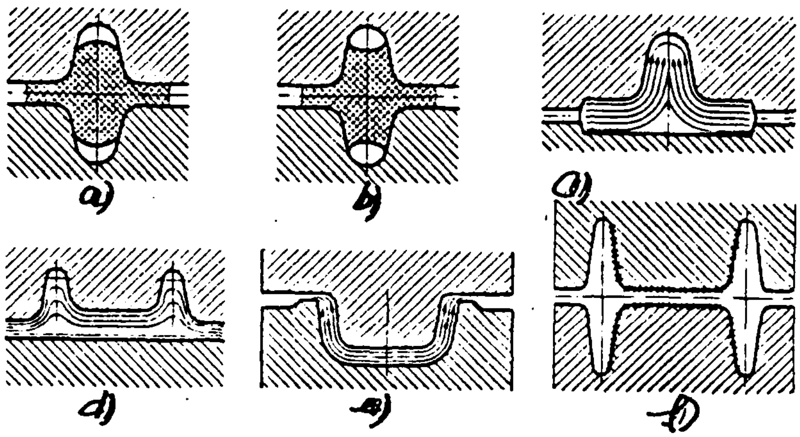

Fig. 7. Diagrams of filling of the die cavity during stamping (xx -- the place of intense wear).

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For the edges/fins of a small height (approximately/exemplarily to 10 mm) the thickness of edge/fin they usually designate 2-4 times of less than the height/altitude due to the difficulty of sinking die with the very narrow cavities (less than 2 mm).

The conditions of filling of the edges/fins of the closed channel sections/cuts depend on the arrangement of parting line. If parting lines are arranged/located on the bottom (Fig. 7d), then the conditions of filling are the same as in the double-T section/cut. If parting line is arranged/located along the top of edges/fins (Fig.

7e), then the conditions of filling of edges/fins become more favorable than for the open sections/cuts. In this case excessive metal flows in the flash not perpendicular to edges/fins, which is considerably better both from the point of view of the retention/preservation/maintaining high mechanical properties in the zone of transition from the fabric to the edge/fin and from the point of view of the prevention of different defects/flaws in the same zone, which occur during the arrangement of parting line on the bottom.

The distance between the edges/fins is the most important structural element/cell, which has a considerable effect on the process of hot die forging. The smallest distance a_{min} between the edges/fins depends mainly on height/altitude h of edge/fin. The higher the edge/fin, the more must be the distance between the edges/fins. With upper edges and insufficient distance between them (Fig. 7f) the projection of die/stamp, which molds fabric, rapidly is worn.

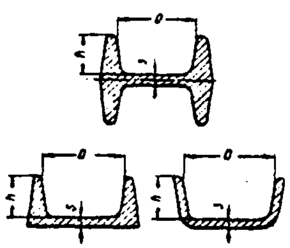
Greatest distance a_{max} between the edges/fins depends in basic on thickness s of the fabric, which connects edges/fins. The thicker the fabric, the more can be the distance between the edges/fins. Limiting values a_{max} and a_{min} are given in Table 3.

At the variable distance between the edges/fins and their constant height/altitude (Fig. 8a) of value a_{min} and a_{max}, those given in table 3, can be respectively reduced and increased by 20%.

In the presence of the hole, whose area composes 50% of area of fabric, the greatest distance between the edges/fins is not limited.

Value which is not smaller, than the relationship/ratio of height/altitude and thickness of edge/fin, has a radius of coupling edge/fin with the fabric. The value of this radius is great for opened and in particular for the closed sections/cuts. With an insufficient radius the couplings in the base/root of the edges/fins of the open sections/cuts are formed their kind of the undercuts (Fig. 8b), which weaken edge/fin and, in addition to this, the conditions of the flowing in of metal into the edge/fin deteriorate.

3. Distance a between the edges/fins in mm.



Высота ребра h (1)	(2) Сплавы					
	Алюминиевые и медные (3)		(4) Магниевые MA2; BM65-1; MA3; MA5		Титановые (5)	
	a_{min}	a_{max}	a_{min}	a_{max}	a_{min}	a_{max}
(6) До 5 (6) Св. 5 до 10 (7) » 10 » 16	10 15	35s	10 12 20	30s	10 12 20	30s
» 16 » 25 » 25 » 35,5	25 85	30s	30 50	25s	30 45	25s
» 35,5 » 50 » 50 » 71 » 71 » 100	50 65 80	25s	70 100 —	20s	60 80 —	20s

Key: (1). Height/altitude of edge/fin h. (2). Alloys. (3). Aluminum and copper. (4). Magnesium. (5). Titanium. (6). To. (7). SV.

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The analogous undercuts of edges/fins with an insufficient radius of coupling are formed in the base/root of the edges/fins of the closed channel sections/cuts with the arrangement of parting line on the top (Fig. 8c). An insufficient radius of coupling in the edges/fins of the closed sections/cuts together with a deterioration in the conditions of their filling leads to the formation of "leakages" in the base/root of the edges/fins (Fig. 8d), which are the consequence of the metal flow into the barb groove above the already filled with metal die cavity, which forms edge/fin.

In the section/cut of any form a radius of coupling is the most strongly worn place for cavity by the force of intensely moving on it metal with the filling of cavity. It is established/installed, that a radius of coupling insufficient in the value very quick-operating, until it reaches some optimum value, with which its state for a long time is stabilized.

Thus, the value of a radius of coupling depends on the shop characteristics of stamping and on a quantity of moving on it metal with the filling of edge/fin; therefore, other conditions being equal, in the open sections/cuts the value of a radius of coupling depends on the height/altitude of edge/fin, and in closed - from the height/altitude of edge/fin and distance between the edges/fins.

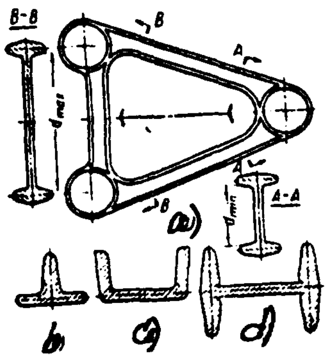
The radii of bending R_1 and R_5 (see drawing/draft in Table 4) are not decisive for the process of shaping, but nevertheless to some degree they affect quality of the blank to be stamped and stability of die/stamp. First of all the bending radii with their insufficient value can lead to formation within the cavity of the cracks of thermal, fatigue or thermal erosion origin.

The small bending radius at the apex/vertex of edge/fin is

badly/poorly filled with metal. Under deformation conditions on the press the place indicated can remain not filled, but during the deformation on the hammer for the clear shaping it requires a large quantity of impacts/shocks, which detrimentally affects both the stability of die and efficiency of the hammer (large quantity of rigid impacts/shocks it is possible to lead to a breakage in the stock/rod of hammer).

The value of the bending radius depends on the depth of cavity.

Radii of transitions R_2 (Fig. 9) have very vital importance. With the filling of edges/fins the metal flow along the edge/fin occurs. With an insufficient radius of coupling in the site of the joint of edges/fins folding and clamps is possible. If a radius of transition couples edge/fin with any massive element of stamping, or it couples two massive elements/cells, then with its insufficient value at the joint the fold, which is the consequence of the nonuniform metal flow with the filling of cavity, is formed.



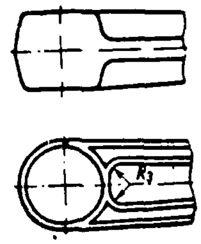


Fig. 8.

Fig. 9.

Fig. 8. Sections/cuts of blanks with variable distance between edges/fins.

Fig. 9. Radii of transitions.

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The value of a radius of transition depends on the height/altitude of the coupled elements of stamping.

The values of the enumerated structural elements/cells for sections/cuts different in the form are given in Table 4-6.

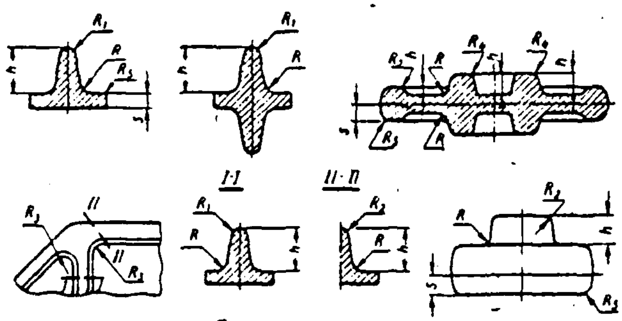
In the tables of the inclination/slope of the fabric of the closed sections/cuts indicated depending on the height/altitude of

edges/fins and distance between them. About the advisability of applying the thickened fabrics it was mentioned in the section about the thickness of the fabrics (see page 96).

It should be pointed out that if in the closed sections/cuts are made the lightening holes, then the sizes/dimensions of structural elements/cells in such sections/cuts (thickness of edge/fin and a radius of coupling edge/fin with the fabric) can be reduced in comparison with the sizes/dimensions of the structural elements of the analogous sections/cuts of not having lightening holes, since the use of a lightening hole as the receiver of excessive metal decreases a quantity of metal, extruded in the flash through the edge/fin.

In the case of the presence in fabric of lightening hole the thickness of edge/fin and a radius of coupling edge/fin with the fabric should be designated according to Tables 8 with the decrease of the distance between the edges/fins to one interval.

4. Radii (in mm) of couplings R, transitions R_3, bending R_1, R_2, R_4 and R_5 and the thickness (in mm) of edges/fins $2R_1$, stamped/die-forged blanks of the aluminum, titanium, copper and magnesium alloys.



(1) Высота ребра или глубина полости h	R	Сплавы (2): титановые, алюминиевые (МА2 и ВМ65-1), медные (3) [R_1]	магниевые (4): МА3	магниевые (4): МА5	R_2	R_3	R_4	Толщина полотна или глубина полости s (5)	R_5
До 5 (6) Св. (7) 5 до 10	3 4	1,5	2		2	5	3	До 5 (6) 5—10	2,0
» 10 (6) » 16	5	2,0		3,5	3	8	4	10—16	2,5
» 16 » 25	8	2,5	2,5		4	10	5	10—25	3,0
» 25 » 35,5 » 35,5 » 50 » 50 » 71 » 71 » 100	10 12,5 15 20	3,0 4,0 5,5 7,0	3,0 4,0 6,0 —	4.0 5.0 6.0 —	5 6 8 10	12,5 15 20 25	6 8 10 12	25—35,5 35,5—50 50—71 71—100	4,0 5,0 7,0 10,0

Key: (1). Height/altitude of edge/fin or the depth of cavity h. (2). Alloys. (3). titanium, aluminum (MA2 and BM65-1), copper. (4). magnesium. (5). Thickness of fabric or depth of cavity. (6). To. (7). SV.

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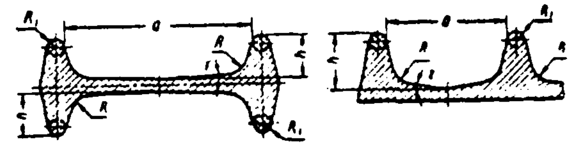
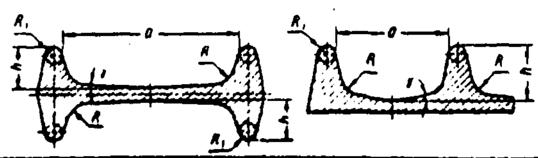
5. Radii of couplings R, bending R_1, thickness of edges/fins $2R_1$ and angles of slope of fabric γ.

А. Алюминиевые, магниевые и медные сплавы (1)



h в мм	a в мм: До 40 (2) R	R₁	γ	40—80 R	R₁	γ	80—125 R	R₁	γ	125—180 R	R₁	γ	180—250 R	R₁	γ	(3) Св. 250 R	R₁	γ
(2) До 5	4	1,5		8	1,5		10	2		—			—					
5—10	5				2					12,5	2,5	1°				—		
10—16	6	2		10	2,5		12,5	2,5			3		15	3				
16—25	8	2,5	—	12,5	3	—		3	2°	15	3,5			4				
25—35,5	10	3		15	3,5		15	3,5			4			4,5		30	5	
35,5—50	12	4		15	4			4		20		1°30'	20	5	1°30'	25	6	
50—71	—			20	4,5		20	5			5		25	6		30	7	1°30'
71—100				25	5		25	6		25	6		30	7		30	8	

Б. Титановые сплавы (4)



h в мм	a в мм: (2) До 40 R	R₁	γ	40—80 R	R₁	γ	80—125 R	R₁	γ	125—180 R	R₁	γ	180—250 R	R₁	γ	(3) Св. 250 R	R₁	γ
(2) До 5	3	1,5		5	1,5	—	10	2		—			—					
5—10	4			6	2		12,5				2	1°				—		
10—16	6	2		10	2,5			2,5			3			3				
16—25	10	2,5	—	12,5	3	2°	15	3	2°	20	3,5		30	4				
25—35,5	—			15				4			4,5	1°30'		5	1°30'	25	6	
35,5—50					4		20	5			6		25	6		30	8	1°30'
50—71				—			25	6		25	8			10			10	

Key: (1). Aluminum magnesium and copper alloys. (2). To. (3). SV. (4). Titanium alloys.

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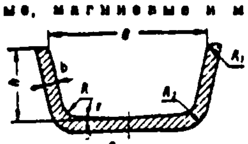
6. Radii of couplings R, bending R_1 and R_2, thickness of wall b angles of slope of fabric γ.

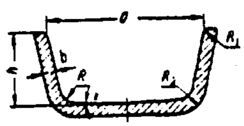
А. Алюминиевые, магниевые и медные сплавы (1)



$R_{2\,min} = \frac{R}{2}$; $R_{2\,max} = R + b$

h в мм	a в мм												
	До 40 (2)				40—80			80—125			(3) Св. 125		
	R_1	R	b	γ	R	b	γ	R	b	γ	R	b	γ
(2) До 10	2	5	2	—	5	3	—	5	4	2°	5	5	1°
10—16		6	2,5		6			6			6	6	
16—25	2,5	8	3,5		8	4,5		8	5,5		8	7	1°30'
25—35,5	3,5	10	4,0		10	6		10	7		10	8	
35,5—50	5	12,5	6		12,5	7		12,5	8		12,5	9	
50—71	6	—			15	8		15	9		15	10	
71—100	7				—			20	10		20	12	
100—140	8							—			25	14	

Б. Титановые сплавы (4)



$R_{2\,min} = \frac{R}{2}$; $R_{2\,max} = R + b$

h в мм	a в мм												
	До 40 (2)				40—80			80—125			(3) Св. 125		
	R_1	R	b	γ	R	b	γ	R	b	γ	R	b	γ
(2) До 10	2	5	3	—	5	4	—	5	4	2°	5	5	1°
10—16		6			6			6	4,5		6	6	
16—25	2,5	8	4		8	5		8	6		8	7	1°30'
25—35,5	3,5	10	5		10	6		10	7		10	8	
35,5—50	5	12,5	6		12,5	7		12,5	8		12,5	9	
50—71	6,5	—			15	8		15	10		15	11	
71—100	8				—			20	12		20	13	

Key: (1). Aluminum, magnesium and copper alloys. (2). To. (3). SV. (4). Titanium alloys.

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Example. Fig. 10a shows the closed sections/cuts of stampings without the lightening holes. A thickness of edge/fin $2R_1$ and a radius of coupling R are assigned according to tables 5 for the height/altitude of edge/fin h=30 mm and distance between the edges/fins a=130 mm.

If we in these sections/cuts fulfill lightening holes, as shown in Fig. 10b, then sizes/dimensions R and R_1 must be designated also according to tables 5 for the height/altitude of edge/fin h=30 mm, but for distance of a between the edges/fins not in the limits of 125-180 mm, as this occurred in the absence of lightening holes, but in the limits of 80-125 mm.

With the variable distance between the edges/fins (Fig. 10c) or at the variable/alternating height/altitude of edge/fin (Fig. 10d, e) the structural elements of section/cut should be determined in terms of the corrected values of distance a_{np} between the edges/fins and heights/altitudes h_{np} of edge/fin, determined from the formulas:

$$a_{np} = \frac{a_{max} + a_{min}}{2}(1 + \sin\alpha);$$

$$h_{np} = \frac{h_{max} + h_{min}}{2}(1 + \sin\alpha) \text{ (1) (для рис. 10, г);}$$

$$h_{np} = 0{,}5h_{max}(1 + \sin\alpha) \text{ (1) (для рис. 10, д).}$$

Key: (1). (for Fig.).

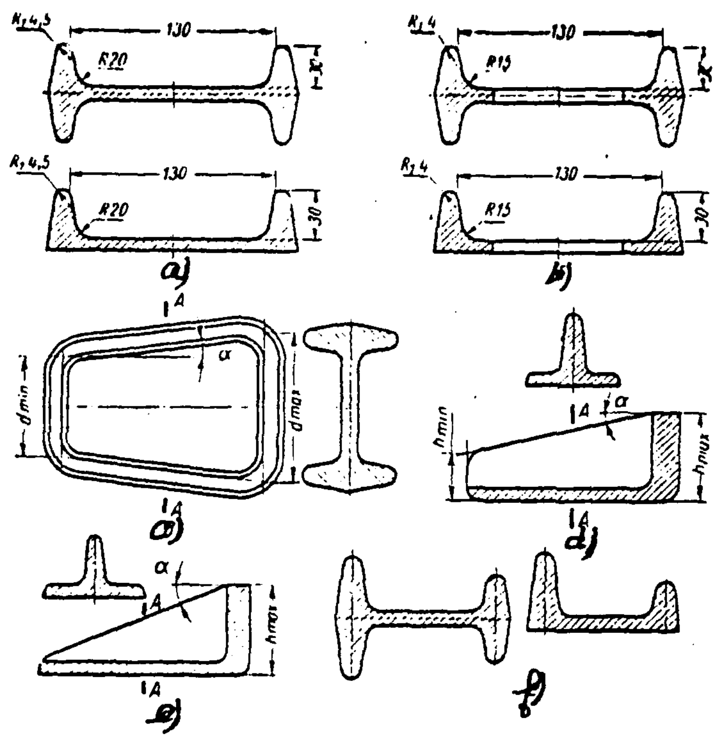

Fig. 10. Closed sections/cuts of blanks.

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The structural elements/cells of parts with the closed sections/cuts and with the dissimilar by the height/altitude edges/fins (Fig. 10f) one should designate as follows: the smallest distance between the edges/fins to select as arithmetic mean of the

distances, determined from the greatest and smallest edges/fins; radii of couplings of edge/fin with the fabric and the thickness of edges/fins select from the greatest edge/fin.

Indentations in the stampings. The thickness of cross connection and the form of indentations in the stampings for the case, when hole is not broached, but indentation is made for the purpose of metal savings, they are determined as follows: with $h \le 0.45$ D (Fig. 11a)

$$a \geqslant 0{,}1D; \quad c \geqslant 0{,}078D;$$
$$r = \frac{D^2}{8h} + \frac{h}{2}$$

value R is determined according to Tables 4 with $0.45D<h<D$ (Fig. 11b)

$$a \geqslant 0{,}1D; \quad r = \frac{D\cos\alpha - 2h\sin\alpha}{2(1-\sin\alpha)}$$

values α and R are determined according to Tables 2 and 4.
when $D < h < 2{,}5D$ (Fig. 11c)

$$c = L - 0{,}6D; \quad a \geqslant 0{,}2D; \quad R_1 = 0{,}2D; \quad R_2 = 0{,}4D$$

values of α and R are determined according to Tables 2 and 4.

The thickness of cross connection and the form of indentation in the stampings for the case, when hole is broached (Fig. 11D), it is determined according to Tables 7 and 8.

Allowances and tolerances.

All stamped/die-forged blanks, as a rule, are subjected to subsequent machining. The degree of accuracy of the

stamped/die-forged blanks is quantitatively determined by two factors: by machining allowances and by tolerances in size.

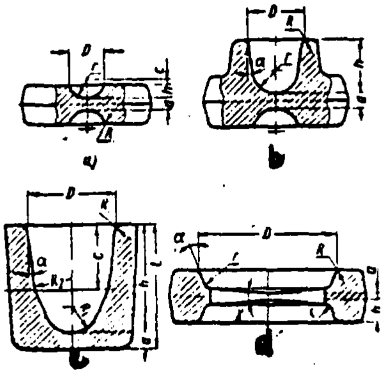

Fig. 11. Thickness of cross connection with the form of indentation in the stampings.

7. Thickness of cross connections in indentations in mm.

D	До 50 (1)	50—80	80—120	120—160	160—200
a	4	6	8	10	12

Key: (1). To.

8. Radii of coupling r into mm and angles of slope γ in deg of cross connections in indentations.

<table>
<tr><th rowspan="3">Глубина выемки в мм (1)</th><th colspan="10">D в мм</th></tr>
<tr><th colspan="2">До 50 (2)</th><th colspan="2">50—80</th><th colspan="2">80—120</th><th colspan="2">120—160</th><th colspan="2">160—200</th></tr>
<tr><th>r</th><th>γ</th><th>r</th><th>γ</th><th>r</th><th>γ</th><th>r</th><th>γ</th><th>r</th><th>γ</th></tr>
<tr><td>(3) До 15</td><td>6</td><td rowspan="7">—</td><td>8</td><td>1</td><td>10</td><td>1</td><td>12</td><td rowspan="2">1</td><td>15</td><td rowspan="2">1</td></tr>
<tr><td>Св. 15 до 30</td><td>8</td><td>10</td><td rowspan="3">2</td><td>12</td><td rowspan="2">2</td><td>15</td><td>20</td></tr>
<tr><td>» 30 » 50</td><td>10</td><td>12</td><td>15</td><td>20</td><td rowspan="2">2</td><td>25</td><td rowspan="2">2</td></tr>
<tr><td>» 50 » 80</td><td rowspan="4">—</td><td>15</td><td>20</td><td rowspan="2">3</td><td>25</td><td>30</td></tr>
<tr><td>» 80 » 120</td><td colspan="2" rowspan="3">—</td><td>25</td><td>30</td><td rowspan="2">3</td><td>35</td><td rowspan="3">3</td></tr>
<tr><td>» 120 » 160</td><td colspan="2" rowspan="2">—</td><td>35</td><td>40</td></tr>
<tr><td>» 160 » 200</td><td colspan="2">—</td><td>50</td></tr>
</table>

Key: (1). Depth of indentation in mm. (2). To. (3). SV.

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From the point of view of technology of forging working shou_ be distinguished two kinds of the allowances: technological and to the machining.

Allowance technological, connected with the need for an increase in the sizes/dimensions of some structural elements of stampings due to their industrial production non-suitability. For example, the section/cut of part, given in Fig. 12, cannot be made by hot-stamping due to the excessively thin fabric, upper edge and insufficient radius of transition from the edge/fin to the fabric. The enumerated structural elements/cells must be increased in this case, which entails the weight increase of part, if we do not tool it. The weight

increase of part in a number of cases is impossible; therefore such parts are worked, although they could go into the matter also concerning the untreated surfaces. Such the allowances, whose value is determined by the possibilities of plastic deformation, have vital importance for the forging production and they are usually called allowances.

Machining allowance (Table 9), connected with the need of achieving of necessary precision/accuracy and purity/finish. The amount of this allowance is determined by the required purity/finish and the precision/accuracy of surface after machining, and also by the distortion of form, which occurs with the hot die forging (displacement, warping/buckling, the negative deviation of tolerance, and also defects/flaws on the surface in the form of flaws, clamps, gas inclusions, etc.).

The amount of allowance they designate according to the largest overall dimension of part, depending on material and required purity/finish.

Tolerances in size. Table 10-19 gives tolerances for different sizes/dimensions of the stamped/die-forged blanks and permissible distortions of their form.

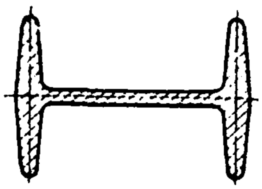

Fig. 12. Section/cut of nontechnological part with the thin fabric.

6. Machining allowance (allowance for side in mm).

Наибольший габаритный размер штамповки в мм (1)	Алюминиевые, магниевые и медные сплавы (2)			Титановые сплавы (3)		
	Класс чистоты обработки (4)					
	4	6	8	4	6	8
(5) До 40	0.80	1,25	1,50	1,00	1,50	1,75
(6) Св. 40 до (5) 60	1,00	1,50	1,75	1,25	1,75	2,00
» 60 » 100	1,25	1,75	2,00	1,50	2,00	2,25
» 100 » 100	1,50	2,00	2,25	1,75	2,25	2,50
» 160 » 250	1,75	2,25	2,50	2,00	2,50	2,75
» 250 » 360	2,00	2,50	3,00	2,25	2,75	3,25
» 360 » 500	2,25	2,75	3,25	2,50	3,00	3,50
» 500 » 630	2,50	3,00	3,50	2,75	3,25	3,75
» 630 » 800	2,75	3,50	4,00	3,00	3,75	4,25
» 800 » 1000	3,00	4,00	4,50	3,50	4,50	5,00
» 1000 » 1250	3,50	4,50	5,00	4,00	5,00	5,50
» 1250 » 1600	4,00	5,00	5,50	4,50	5,50	6,00
» 1600 » 2000	4,50	5,50	6,25	5,25	6,25	7,00
» 2000 » 2500	5,25	6,25	7,00	6,00	7,00	7,75
» 2500 » 3150	6,00	7,00	8,00	7,00	8,00	9,00
» 3150 » 4000	7,00	8,00	9,00	8,00	9,00	10,00
» 4000 » 5000	8,00	9,00	10,00	9,00	10,00	11,00
» 5000 » 6300	9,00	10,00	11,00	10,00	11,00	12,00
» 6300 » 8000	10,00	11,00	12,00	11,00	12,00	13,00

Key: (1). Largest overall dimension of stamping in mm. (2). Aluminum, magnesium and copper alloys. (3). Titanium alloys. (4). Class of purity/finish of working. (5). To. (6). SV.

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10. Tolerances for vertical (perpendicular parting planes) sizes/dimensions of stamped blanks (bilateral wear).

Площадь проекции штампованной заготовки на плоскость разъема штампа в см² (1)	Классы точности (2) / Отклонения в мм (3) / Для штамповок из алюминиевых магниевых и медных сплавов (4)						Для штамповок из титановых сплавов (5)					
	4		5		6		4		5		6	
	верхн. (6)	нижн. (7)	верхн. (6)	нижн. (7)	верхн. (6)	нижн. (7)	верхн. (6)	нижн. (7)	верхн. (6)	нижн. (7)	верхн. (6)	нижн. (7)
До (8) 6,0	+0.2	−0.1	+0.3	−0.15	+0.5	−0.2	+0.3	−0.15	+0.4	−0.2	+0.6	−0.3
Св. (9) 6,0 до (8) 10	+0.25	−0.12	+0.35	−0.2	+0.6	−0.3	+0.35	−0.15	+0.5	−0.2	+0.7	−0.3
» 10 » 16	+0.3	−0.15	+0.4	−0.2	+0.7	−0.3	+0.4	−0.2	+0.6	−0.3	+0.8	−0.4
» 16 » 25	+0.35	−0.15	+0.5	−0.3	[illegible]	−0.4	+0.45	−0.2	+0.7	−0.3	+1.0	−0.5
» 25 » 40	+0.4	−0.2	+0.6	−0.3	+1.0	−0.5	+0.5	−0.3	+0.8	−0.4	+1.2	−0.6
» 40 » 80	+0.5	−0.3	+0.8	−0.4	+1.2	−0.6	+0.6	−0.3	+1.0	−0.5	+1.5	−0.6
» 80 » 160	+0.6	−0.3	+1.0	−0.5	+1.5	−0.7	+0.8	−0.4	+1.2	−0.6	+2.0	−0.8
» 160 » 320	+0.8	−0.4	+1.2	−0.5	+2.0	−0.8	+1.0	−0.5	+1.5	−0.7	+2.5	−1.0
» 320 » 480	+1.0	−0.5	+1.5	−0.6	+2.5	−1.0	+1.2	−0.6	+1.8	−0.8	+3.0	−1.2
» 480 » 800	+1.2	−0.6	+1.8	−0.7	+3.0	−1.2	+1.5	−0.8	+2.2	−1.0	+3.5	−1.5
» 800 » 1 250	+1.4	−0.7	+2.1	−0.8	+3.5	−1.5	+1.8	−0.9	+2.6	−1.2	+4.0	−1.6
» 1 250 » 1 700	+1.6	−0.8	+2.4	−1.0	+4.0	−1.8	+2.1	−1.0	+3.0	−1.4	+4.5	−2.0
» 1 700 » 2 240	+1.8	−0.9	+2.8	−1.2	+4.5	−2.0	+2.4	−1.2	+3.5	−1.6	+5.0	−2.5
» 2 240 » 3 000	+2.1	−1.0	+3.2	−1.4	+5.0	−2.2			+4.0	−1.8	+6.0	−2.5
» 3 000 » 4 000	+2.4	−1.2	+3.6	−1.6	+5.5	−2.5	—		+4.5	−2.1	+6.5	−3.0
» 4 000 » 5 300	+2.7	−1.3	+4.0	−1.8	+6.0	−2.8			+5.0	−2.4	+7.5	−3.0
» 5 300 » 6 300	+2.9	−1.4	+4.3	−1.9	+6.5	−3.0						
» 6 300 » 8 000	+3.2	−1.6	+4.8	−2.2	+7.1	−3.2						
» 8 000 » 10 000	+3.6	−1.8	+5.3	−2.4	+7.7	−3.5						
» 10 000 » 12 500	+3.9	−1.9	+5.8	−2.7	+8.4	−3.8			—			
» 12 500 » 16 000	+4.3	−2.1	+6.4	−3.0	+9.2	−4.2						
» 16 000 » 20 000	+4.8	−2.4	+7.1	−3.3	+10.0	−4.5						
» 20 000 » 25 000	+5.3	−2.8	+7.8	−3.7	+11.0	−5.0						

Key: (1). Projected area of the stamped/die-forged blank on the parting plane of die/stamp in cm². (2). Classes of precision. (3). Deviations in mm. (4). For stampings from aluminum magnesium and copper alloys. (5). For stampings from titanium alloys. (6). upper. (7). lower. (8). To. (9). SV.

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11. Tolerances for vertical (perpendicular parting planes) sizes/dimensions of stamped/die-forged blanks (wear in one direction).

Площадь проекции штампованной заготовки на плоскость разъема штампа в см² (1)	(2) Классы точности											
	4		5		6		4		5		6	
	(3) Отклонения в мм											
	Для штамповок из алюминиевых, магниевых и медных сплавов (4)						Для штамповок из титановых сплавов (5)					
	(6) верхн	(7) нижн	(6) верхн	(7) нижн	(6) верхн	(7) нижн	(6) верхн	(7) нижн	(6) верхн	(7) нижн	(6) верхн	(7) нижн
(8) До 6,0	+0.05	−0.10	+0.06	−0.15	+0.10	−0.25	+0.05	−0.15	+0.10	−0.20	+0.15	−0.30
Св. (9) 6,0 до (8) 10	+0.06	−0.12	+0.10	−0.18	+0.13	−0.30	+0.06	−0.18	+0.10	−0.25	+0.15	−0.35
» 10 » 16	+0.08	−0.15	+0.12	−0.20	+0.18	−0.35	+0.10	−0.20	+0.15	−0.30	+0.20	−0.40
» 16 » 25	+0.08	−0.17	+0.15	−0.25	+0.20	−0.40	+0.10	−0.23	+0.15	−0.35	+0.25	−0.50
» 25 » 40	+0.10	−0.20	+0.17	−0.30	+0.24	−0.50	+0.15	−0.25	+0.20	−0.40	+0.30	−0.60
» 40 » 80	+0.12	−0.25	+0.20	−0.40	+0.28	−0.60	+0.15	−0.30	+0.25	−0.50	+0.40	−0.75
» 80 » 160	+0.15	−0.30	+0.23	−0.50	+0.30	−0.75	+0.20	−0.40	+0.30	−0.60	+0.40	−1.00
» 160 » 320	+0.20	−0.40	+0.26	−0.60	+0.35	−1.00	+0.25	−0.50	+0.35	−0.75	+0.50	−1.[illegible]
» 320 » 480	+0.25	−0.50	+0.30	−0.80	+0.40	−1.30	+0.30	−0.60	+0.40	−0.90	+0.60	−1.[illegible]
» 480 » 800	+0.30	−0.60	+0.35	−0.90	+0.50	−1.50	+0.40	−0.75	+0.50	−1.10	+0.75	−1.75
» 800 » 1 250	+0.35	−0.70	+0.40	−1.00	+0.60	−1.80	+0.45	−0.90	+0.60	−1.30	+0.90	−2.00
» 1 250 » 1 700	+0.40	−0.80	+0.50	−1.20	+0.70	−2.00	+0.50	−1.00	+0.70	−1.50	+1.00	−2.25
» 1 700 » 2 240	+0,45	−0,90	+0,60	−1,40	+0.80	−2.30	+0.60	−1.20	+0.80	−1.75	+1.25	−2.50
» 2 240 » 3 000	+0.50	−1.00	+0.70	−1.60	+0.90	−2.50	—		+0.90	−2.00	+1.25	−3.00
» 3 000 » 4 000	+0.60	−1.20	+0.80	−1.80	+1.10	−2.80			+1.00	−2.25	+1.50	−3.25
» 4 000 » 5 300	+0.65	−1.40	+0.90	−2.00	+1.20	−3.00			+1.20	−2.50	+1.50	−3.75
» 5 300 » 6 300	+0.70	−1.50	+1.00	−2.20	+1.30	−3.30	—					
» 6 300 » 8 000	+0.80	−1.60	+1.10	−2.40	+1.50	−3.50						
» 8 000 » 10 000	+0.90	−1.80	+1.20	−2.60	+1.60	−3.80						
» 10 000 » 12 500	+1,00	−2.00	+1.30	−2.90	+1.80	−4.20						
» 12 500 » 16 000	+1.10	−2.20	+1.50	−3.20	+1.90	−4.80						
» 16 000 » 20 000	+1.20	−2.40	+1.70	−3.50	+2.10	−5.00						
20 000 » 25 000	+1.30	−2.60	+1.90	−3.90	+2.30	−5.50						

Key: (1). Projected area of the stamped/die-forged blank on the parting plane of die/stamp in cm². (2). Classes of precision. (3). Deviations in mm. (4). For stampings from aluminum, magnesium and copper alloys. (5). For stampings from titanium alloys. (6). upper. (7). lower. (8). To. (9). SV.

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12. Tolerances for horizontal (parallel parting planes) sizes/dimensions of stamped/die-forged blanks (bilateral wear).

(1) Размер штампованной заготовки в мм	(2) Классы точности											
	4		5		6		4		5		6	
	(3) Отклонения в мм											
	(4) Для штамповок из алюминиевых, магниевых и медных сплавов						(5) Для штамповок из титановых сплавов					
	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.
(8) До 16	+0.3	−0.15	+0.4	−0.2	+0.5	−0.3	+0.4	−0.2	+0.5	−0.3	+0.7	−0.4
(9) Св. 16 до 25	+0.4	−0.2	+0.5	−0.25	+0.6	−0.4	+0.5	−0.3	+0.6	−0.3	+0.8	−0.4
» 25 » 40	+0.5	−0.25	+0.6	−0.35	+0.7	−0.45	+0.6	−0.3	+0.8	−0.4	+1.0	−0.5
» 40 » 60	+0.6	−0.3	+0.8	−0.4	+0.9	−0.6	+0.8	−0.4	+1.0	−0.5	+1.2	−0.8
» 60 » 100	+0.8	−0.4	+1.0	−0.6	+1.2	−0.8	+1.0	−0.6	+1.2	−0.8	+1.5	−1.0
» 100 » 160	+1.0	−0.6	+1.2	−0.8	+1.5	−1.0	+1.2	−0.8	+1.5	−1.0	+1.8	−1.2
» 160 » 250	+1.2	−0.8	+1.5	−1.0	+2.0	−1.2	+1.5	−1.0	+1.8	−1.2	+2.1	−1.5
» 250 » 360	+1.5	−1.0	+1.8	−1.2	+2.5	−1.5	+1.8	−1.2	+2.1	−1.5	+2.5	−1.8
» 360 » 500	+1.8	−1.2	+2.1	−1.5	+3.0	−2.0	+2.1	−1.5	+2.5	−1.8	+3.0	−2.2
» 500 » 630	+2.1	−1.4	+2.4	−1.8	+3.5	−2.2	+2.4	−1.8	+3.0	−2.0	+3.5	−2.5
» 630 » 800	+2.4	−1.6	+2.7	−2.0	+4.0	−2.5	+2.7	−2.1	+3.3	−2.5	+4.0	−3.0
» 800 » 1000	+2.7	−1.8	+3.0	−2.4	+4.5	−3.0	+3.1	−2.4	+4.0	−3.0	+4.5	−3.5
» 1000 » 1250	+3.0	−2.0	+3.5	−2.8	+5.0	−3.5	+3.5	−2.8	+4.5	−3.5	+5.0	−4.0
» 1250 » 1600	+3.3	−2.3	+4.0	−3.2	+5.5	−4.0	—	—	+5.0	−4.0	+6.0	−5.0
» 1600 » 2000	+3.6	−2.6	+4.5	−3.6	+6.0	−4.5	—	—	+5.5	−4.5	+7.0	−6.0
» 2000 » 2500	+4.0	−3.0	+5.0	−4.0	+6.5	−5.0	—	—	+6.0	−5.0	+6.0	−7.0
» 2500 » 3150	+4.5	−3.3	+5.9	−4.5	+7.6	−5.8	—	—	—	—	—	—
» 3150 » 4000	+5.0	−3.7	+6.7	−5.2	+8.6	−6.7	—	—	—	—	—	—
» 4000 » 5000	+5.6	−4.2	+7.5	−5.9	+9.7	−7.6	—	—	—	—	—	—
» 5000 » 6300	+6.2	−4.8	+8.4	−6.7	+10.9	−8.7	—	—	—	—	—	—
» 6300 » 8000	+6.9	−5.4	+9.5	−7.6	+12.4	−10.0	—	—	—	—	—	—

Key: (1). Size/dimension of the stamped/die-forged blank in mm. (2). Classes of precision. (3). Deviations in mm. (4). For stampings from aluminum, magnesium and copper alloys. (5). For stampings from titanium alloys. (6). upper. (7). lower. (8). To. (9). SV.

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13. Tolerances for horizontal (parallel parting planes) sizes/dimensions of stamped/die-forged blanks (not depending on wear).

Размер штампованной заготовки в мм (1)	(2) Классы точности — (3) Отклонения в мм: Для штамповок из алюминиевых, магниевых и медных сплавов (4) — 4 верхн (6)	4 нижн (7)	5 верхн. (6)	5 нижн. (7)	6 верхн. (6)	6 нижн. (7)	Для штамповок из титановых сплавов (5) — 4 верхн. (6)	4 нижн. (7)	5 верхн. (6)	5 нижн. (7)	6 верхн (6)	6 нижн. (7)
До 16 (8)	+0.06	−0.06	+0.10	−0.10	+0.15	−0.15	+0.10	−0.10	+0.15	−0.15	+0.20	−0.20
Св (9) 16 до (8) 25	+0.06	−0.06	+0.12	−0.12	+0.16	−0.18	+0.12	−0.12	+0.18	−0.18	+0.25	−0.25
» 25 » 40	+0.10	−0.10	+0.15	−0.15	+0.20	−0.20	+0.15	−0.15	+0.22	−0.22	+0.30	−0.30
» 40 » 60	+0.12	−0.12	+0.20	−0.20	+0.30	−0.30	+0.18	−0.18	+0.27	−0.27	+0.35	−0.35
» 60 » 100	+0.18	−0.18	+0.30	−0.30	+0.50	−0.50	+0.25	−0.25	+0.35	−0.35	+0.50	−0.50
» 100 » 160	+0.25	−0.25	+0.40	−0.40	+0.60	−0.60	+0.35	−0.35	+0.50	−0.50	+0.70	−0.70
» 160 » 250	+0.35	−0.35	+0.50	−0.50	+0.80	−0.80	+0.50	−0.50	+0.70	−0.70	+1.00	−1.00
» 250 » 360	+0.50	−0.50	+0.80	−0.80	+1.20	−1.20	+0.65	−0.65	+0.90	−0.90	+1.30	−1.30
» 360 » 500	+0.65	−0.65	+1.00	−1.00	+1.50	−1.50	+0.80	−0.80	+1.20	−1.20	+1.70	−1.7
» 500 » 630	+0.85	−0.85	+1.20	−1.20	+1.80	−1.80	+1.00	−1.00	+1.50	−1.50	+2.10	−2.10
» 630 » 800	+1.00	−1.00	+1.50	−1.50	+2.20	−2.20	+1.25	−1.25	+1.80	−1.80	+2.50	−2.50
» 800 » 1000	+1.30	−1.30	+1.50	−1.80	+2.60	−2.60	+1.50	−1.50	+2.10	−2.10	+3.00	−3.00
» 1000 » 1250	+1.50	−1.50	+2.10	−2.10	+3.00	−3.00	+1.80	−1.80	+2.50	−2.50	+3.50	−3.50
» 1250 » 1600	+1.80	−1.80	+2.50	−2.50	+3.50	−3.50	+2.10	−2.10	+3.00	−3.00	+4.00	−4.00
» 1600 » 2000	+2.10	−2.10	+3.00	−3.00	+4.00	−4.00	+2.50	−2.50	+3.50	−3.50	+4.50	−4.50
» 2000 » 2500	+2.40	−2.40	+3.50	−3.50	+4.50	−4.50	+3.00	−3.00	+4.00	−4.00	+5.00	−5.00
» 2500 » 3150	+2.80	−2.80	+4.00	−4.00	+5.00	−5.00						
» 3150 » 4000	+3.40	−3.40	+4.50	−4.50	+5.60	−5.60						
» 4000 » 5000	+4.00	−4.00	+5.10	−5.10	+6.20	−6.20						
» 5000 » 6300	+4.50	−4.50	+5.80	−5.80	+7.00	−7.00						
» 6300 » 8000	+5.00	−5.00	+6.50	−6.50	+8.00	−8.00						

Key: (1). Size/dimension of the stamped/die-forged blank in mm. (2). Class of precision. (3). Deviations in mm. (4). For stampings from aluminum, magnesium and copper alloys. (5). For stampings from titanium alloys. (6). upper. (7). lower. (8). To. (9). SV.

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14. Tolerances in size of uncoordinated technological radii of stamped/die-forged blanks.

(1) Номинальный размер радиуса в мм	(2) Классы точности											
	4		5		6		4		5		6	
	(3) Отклонения в мм											
	(4) Для штамповок из алюминиевых, магниевых и медных сплавов						(5) Для штамповок титановых сплавов					
	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.	(6) верхн.	(7) нижн.
2,5	+1,0	−0,5	+1,5	−0,5	–	–	+1,5	−0,5	+2,0	−0,5	–	–
3,0	+1,5	−0,5	+2,0	−1,0	–	–	+2,0	−0,5	+2,5	−1,0	–	–
4,0	+2,0	−1,0	+2,5	−1,0	–	–	+2,5	−1,0	+3,0	−1,0	–	–
5,0	+2,0	−1,0	+2,5	−1,0	+3,0	−1,5	+2,5	−1,5	+3,0	−1,5	+3,5	−2,0
6,0	+2,5	−1,0	+3,0	−1,5	+3,5	−2,0	+3,0	−1,5	+3,5	−2,0	+4,5	−2,0
8,0	+3,0	−1,5	+3,5	−2,0	+4,0	−2,0	+3,5	−2,0	+4,5	−2,0	+5,0	−2,5
10	+3,0	−1,5	+4,0	−2,0	+5,0	−2,5	+4,0	−2,0	+5,0	−2,5	+6,0	−3,0
12,5	+3,5	−1,5	+4,5	−2,0	+5,5	−2,5	+4,5	−2,0	+5,5	−2,5	+6,5	−3,0
15	+3,5	−2,0	+4,5	−2,5	+6,0	−3,0	+4,5	−2,5	+5,5	−3,0	+7,0	−3,5
20	+4,0	−2,0	+5,0	−2,5	+6,5	−3,5	+5,0	−2,5	+6,0	−3,0	+7,5	−3,5
25	+4,0	−2,0	+5,0	−2,5	+7,0	−3,5	+5,0	−3,0	+6,5	−3,5	+8,0	−4,0
30	+4,5	−2,5	+5,5	−3,0	+7,5	−3,5	+5,5	−3,0	+7,0	−3,5	+8,5	−4,0
35	+5,0	−2,5	+6,0	−3,0	+7,5	−4,0	+6,0	−3,0	+7,5	−3,5	+8,5	−4,5
40	+5,5	−3,0	+6,5	−3,5	+8,0	−4,0	+6,5	−3,0	+7,5	−4,0	+9,0	−4,5
45	+5,5	−3,0	+7,0	−3,5	+8,5	−4,5	+6,5	−3,5	+8,0	−4,0	+9,5	−5,0
50	+6,0	−3,0	+7,5	−4,0	+9,0	−4,5	+7,0	−3,5	+8,5	−4,5	+10	−5,0

Key: (1). Nominal size of a radius in mm. (2). Classes of precision. (3). Deviations in mm. (4). For stampings from aluminum, magnesium and copper alloys. (5). For stampings of titanium alloys. (6). upper. (7). lower.

15. Permissible displacement (in mm) on the split plane of die/stamp for stamped/die-forged blanks.

Площадь проекции штампованной заготовки на плоскость разъема штампа в см² (1)	(2) Классы точности			Площадь проекции штампованной заготовки на плоскость разъема штампа в см² (1)	(2) Классы точности		
	4	5	6		4	5	6
До 6 (3)	0,16	0,20	0,30	(4) Св. 1 700 до 2 240	1,40	2,00	2,00
(4) Св. 6 до (3) 10	0,16	0,25	0,35	» 2 240 » 3 000	1,00	2,20	2,00
» 10 » 16	0,20	0,30	0,40	» 3 000 » 4 000	1,80	2,40	3,00
» 16 » 25	0,24	0,35	0,50	» 4 000 » 5 300	2,00	2,60	3,30
» 25 » 40	0,28	0,40	0,60	» 5 300 » 6 300	2,20	2,80	3,60
» 40 » 80	0,30	0,50	0,80	» 6 300 » 8 000	2,50	3,10	4,00
» 80 » 160	0,40	0,66	1,00	» 8 000 » 10 000	2,80	3,40	4,40
» 160 » 320	0,50	0,80	1,20	» 10 000 » 12 500	3,10	3,80	4,80
» 320 » 480	0,60	1,00	1,50	» 12 500 » 16 000	3,40	4,20	5,20
» 480 » 800	0,80	1,20	1,80	» 16 000 » 20 000	3,70	4,80	5,60
» 800 » 1250	1,00	1,50	2,10	» 20 000 » 25 000	4,00	5,00	6,00
» 1250 » 1700	1,20	1,80	2,40				

Key: (1). Projected area of the stamped/die-forged blank on the parting plane of die/stamp in cm². (2). Classes of precision. (3). To. (4). SV.

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16. Permissible warping/buckling (in mm) of stamped/die-forged

Наибольший габаритный размер штампованной заготовки в мм (1)	(2) Классы точности					
	4	5	6	4	5	6
	Для штамповок из алюминиевых, магниевых и медных сплавов (3)			(4) Для штамповок из титановых сплавов		
(5) До 16	0,10	0,15	0,25	0,2	0,3	0,4
(6) Св. 16 до 25 (5)	0,15	0,20	0,30	0,25	0,4	0,5
» 25 » 40	0,20	0,30	0,35	0,3	0,5	0,6
» 40 » 60	0,25	0,30	0,40	0,4	0,6	0,8
» 60 » 100	0,30	0,40	0,50	0,45	0,7	1,0
» 100 » 160	0,35	0,50	0,65	0,5	0,8	1,2
» 160 » 250	0,40	0,60	0,80	0,6	0,9	1,4
» 250 » 360	0,45	0,70	1,00	0,7	1,0	1,6
» 360 » 500	0,50	0,80	1,20	0,8	1,2	1,8
» 500 » 630	0,60	0,90	1,40	0,9	1,3	2,0
» 630 » 800	0,70	1,00	1,60	1,1	1,5	2,2
» 800 » 1000	0,80	1,20	1,80	1,3	1,8	2,7
» 1000 » 1250	0,95	1,40	2,10	1,5	2,2	3,3
» 1250 » 1600	1,10	1,60	2,40	1,7	2,5	3,8
» 1600 » 2000	1,30	1,80	2,70	2,0	3,0	4,5
» 2000 » 2500	1,50	2,20	3,30	2,5	3,5	5,0
» 2500 » 3150	1,70	2,60	3,60		—	
» 3150 » 4000	2,00	3,00	4,50			
» 4000 » 5000	2,50	4,00	6,00			
» 5000 » 6300	3,00	5,00	8,00			
» 6300 » 8000	4,00	6,00	10,00			

Key: (1). Largest overall dimension of the stamped/die-forged blank in mm. (2). Classes of precision. (3). For stampings from aluminum, magnesium and copper alloys. (4). For stampings from titanium alloys. (5). To. (6). SV.

17. Tolerances for drafts of stamping blanks.

Номинальный размер штамповочного уклона в град (1)	(2) Классы точности					
	4		5		6	
	(3) Отклонения					
	верхн. (4)	нижн. (5)	верхн. (4)	нижн. (5)	верхн. (4)	нижн. (5)
3	+0°30′	−0°30′	+1°00′	−1°00′	+1°30′	−1°30′
5	+0°30′	−0°30′	+1°00′	−1°30′	+1°30′	−1°30′
7	+0°45′	−0°45′	+1°00′	−1°30′	+1°30′	−1°30′
10	+1°00′	−1°00′	+1°30′	−1°00′	+2°00′	−1°30′
12	+1°30′	−1°00′	+2°00′	−1°30′	+3°00′	−2°00′
15	+2°00′	−1°30′	+3°00′	−2°00′	+4°00′	−3°00′

Key: (1). Nominal size of draft in deg. (2). Classes of precision. (3). Deviations. (4). upper. (5). lower.

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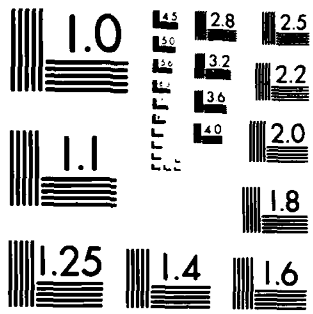

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In them are provided for three classes of the precision: by the 4th, the 5th and the 6th (first three classes they are reserved for the stampings, obtained on the special technological processes).

The 4th class of precision is intended for determining the maximum deviations of the sizes/dimensions between the nontreatable surfaces of the structural elements of technologically effective stampings, i.e., the stampings, finished in accordance with the given is above recommendations.

Deviations with respect to the 4th class of precision cannot be designated to the following structural elements of stampings:

to the thickness of the fabrics of the closed sections/cuts (double-T channel) in the distance ratio a between the edges/fins to thickness s of fabric it is higher than 15 for the stampings from the aluminum alloys and in the absence of possibility of designing on the fabric of receiver for the removal/distance of excessive metal in the

form of lightening hole or in the form of thickening, which is removed by machining;

to the thickness of the fabrics of the open sections/cuts (T-shaped) and cross-shaped in the ratio of the width of fabric to thickness b/s>20;

to the thickness of the fabrics of flat/plane sections/cuts with b/s>15.

Tolerances according to the 4th class of precision can be ensured with the observance of the following conditions:

The correct distribution of the material of the initial blank of shaped ductile on the hammers or with upsetting in the horizontal forging machines;

by use of hot sizing;

the 5th class of precision is intended for determining the maximum deviations of the sizes/dimensions between the non-machined surfaces of the technologically effective stampings of all configurations (without the limitations, accepted for stampings of the 4th class of precision).

The observance of the same conditions is required for

achievement of tolerances according to the 5th class of precision as for the tolerances according to the 4th class with exception of the use/application of hot calibration.

The 6th class of precision is intended for determining the maximum deviations of the sizes/dimensions between the machined surfaces of stampings of all configurations. Tolerances according to the 6th class of precision can be achieved/reached by the common methods of forging working.

18. Manufacturing tolerance (in mm) from the axial alignment of the broached holes in the stamped/die-forged blanks.

(1) Наибольший размер штампованной заготовки в мм	(2) Классы точности		
	4	5	6
(3) До 60	0,5	0,8	1,2
(4) Св. 60 (3) до 100	0,6	1,0	1,5
» 100 » 160	0,8	1,5	2,5
» 100 » 250	1,2	2,0	3,0
» 250 » 300	1,6	2,5	3,6
» 300 » 500	2,0	3,0	4,2
» 500 » 630	2,5	3,5	4,8
» 630 » 800	3,0	4,0	5,5

Key: (1). the maximum size of the stamped/die-forged blank in mm. (2). Classes of precision. (3). To. (4). Higher than.

19. Permissible remainder/residue from flash (in mm) on perimeter of shear/section of stamped/die-forged blanks.

(1) Наибольший габаритный размер штампованной заготовки в мм	(2) Классы точности		
	4	5	6
(3) 25 (4)	0,2	0,3	0,5
Св. 25 до 40	0,3	0,4	0,6
» 40 » 60	0,4	0,6	0,8
» 60 » 100	0,6	0,9	1,3
» 100 » 160	0,8	1,2	1,7
» 160 » 250	1,0	1,5	2,0
» 250 » 360	1,2	1,8	2,4
» 360 » 500	1,4	2,0	2,8
» 500 » 630	1,6	2,3	3,2
» 630 » 800	1,8	2,7	3,6
» 800 » 1000	2,0	3,0	4,0
» 1000 » 1250	2,3	3,4	4,5
» 1250 » 1600	2,6	3,8	5,0
» 1600 » 2000	3,0	4,6	5,5
» 2000 » 2500	3,5	5,0	6,0

The notes: 1 - with the cutting of flash on the saw bands is allowed/assumed the following remainder/residue from flash at the length of the stamped/die-forged blanks to 1000 mm - 3 mm, above 1000 mm - 6 mm.

2. Remainder/residue from flash to 20 mm is allowed in places of roundings.

Key: (1). Largest overall dimension of the stamped/die-forged blank in mm. (2). Classes of precision. (3). above (4). to.

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Designation/purpose of tolerances. With the designation/purpose of manufacturing tolerances it is necessary to be guided by the following positions (Fig. 13):

1) if dimensions H and s are vertical, determine the thickness of the stamped/die-forged blank and cause the bilateral wear of dies/stamps, then tolerances on them are determined depending on the projected area of the stamped/die-forged blank on the parting plane of die/stamp (Table 10);

2) if sizes/dimensions h and h_1 vertical, determine the depth of indentation in the stamped/die-forged blank and cause the wear of die/stamp in one direction, then tolerances on them are determined depending on the projected area of the stamped/die-forged blank on

the parting plane of die/stamp and following conditions; if the bottom of deepening (h) is not removed by gap or machining - according to Table 11; if the bottom of deepening (h_1) is removed by gap or machining - according to Table 10 (with the opposite sign);

3) if sizes/dimensions D horizontal, determine length or width of the stamped/die-forged blank or its element/cell and cause the bilateral wear of dies/stamps, then tolerances on them are determined depending on the value of the corresponding size/dimension according to Table 12;

4) if sizes/dimensions d horizontal, determine length and wic of indentation in the stamped/die-forged blank they cause the bilateral wear of die/stamp, then tolerance value for them, indicated in Table 12, they are accepted with the opposite sign;

5) if sizes/dimensions L and L_1 horizontal and cause the one-sided wear of dies/stamps, then tolerances on them are determined by half tolerance value for the doubled size/dimension (2L or $2L_1$), undertaken according to Table 12. For size/dimension of L the tolerance is taken with the same sign, while for L_1 with the reverse/inverse;

6) if sizes/dimensions A and l are horizontal, determine

distance between centers of bosses or other elements/cells or cause the wear of dies/stamps in one direction, then tolerances on them are determined depending on the value of the corresponding size/dimension according to Table 13;

7) for the noncoordinated technological radii R tolerances are determined depending on the value of a radius according to Table 14;

8) displacement tolerances of the stamped/die-forged blanks in the parting plane of die/stamp are set depending on the projected area of the stamped/die-forged blank on the parting plane of die/stamp according to Table 15. Displacement tolerances do not depend on other tolerances and are addition to them;

9) the permissible warping/buckling (curvature, sagging/deflection) is set to the largest overall dimension of the stamped/die-forged blank according to Table 16. Tolerances for the warping/buckling do not depend on other tolerances and are addition to them;

10) tolerances for drafts are determined depending on the value of draft according to Table 17. Tolerances for drafts do not depend on other tolerances and are addition to them.

11) manufacturing tolerance from the axial alignment of the broached holes is determined depending on the largest overall dimension of the stamped/die-forged blank according to Table 18;

12) the permissible value of remainder/residue from the flash is set to the largest overall dimension of the stamped/die-forged blank and the method of trimming according to Table 19.

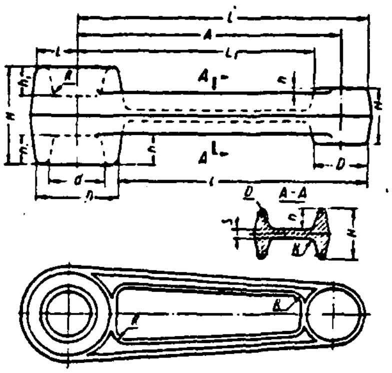

Fig. 13. Sizes/dimensions of blank for the designation/purpose of manufacturing tolerances (tolerances).

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Remainder on flash does not depend on other tolerances and is addition to them;

13) tolerances for dimensions are entered/written in the numerical values;

14) depending on the manufacturability of the separate elements of the stamped/die-forged blanks tolerances in size of these elements/cells can be designated according to different classes of precision;

15) if the section/cut of the stamped/die-forged blank in the plane, perpendicular to joint, has a form of wheel/circle, then tolerance for the diameter of this wheel/circle can be defined both to the vertical (according to Table 10) and horizontal (according to Table 12) sizes/dimensions. Is accepted that of them, whose field is more;

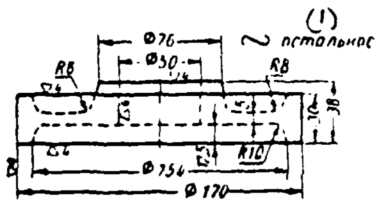
16) tolerances in size, which are absent from the drawing of the stamped/die-forged blank, but they can be designed on the basis of the available sizes/dimensions, they are determined according to the appropriate tables, but not by summation or by the subtraction of tolerances for the separate sizes/dimensions;

17) sometimes in the production of the stamped/die-forged billets for the parts with the large and thin fabrics, or in the absence of the deforming equipment of necessary power tolerances in size can be designated not according to present tables, but according to the agreement of client and user.

Examples of the calculation of tolerances and allowances for stampings. Example 1. Fig. 14 gives the drawing of the machined cover/cap from the aluminum alloy AK6 (AMTU 262-55). To the machining is assigned the allowance 1.75 mm to the side (according to Table 9, for the aluminum alloys at the frequency of the working ∇ 4 and with

the largest overall dimension of 173.5 mm).

Fig. 15 gives the drawing of the stamped/die-forged blank for the same part.



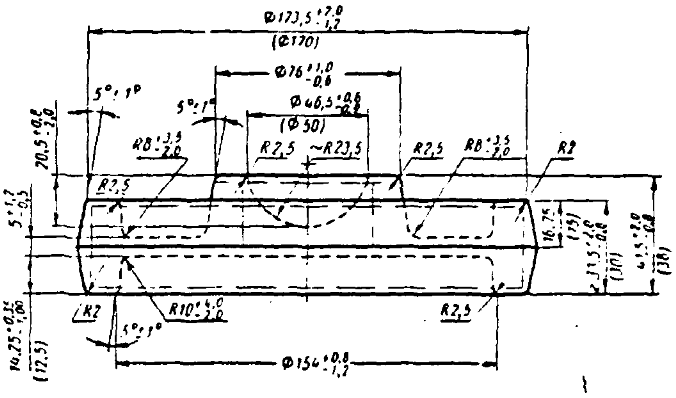


Fig. 14. Fig. 15.

Fig. 14. Drawing of cover/cap.

Key: (1). Rest.

Fig. 15. Drawing of blank for cover/cap.

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Are assigned the following tolerances:

for the horizontal sizes/dimensions:

on diameter $173{,}5^{+2.0}_{-1.2}$ (Table 12 for the sizes/dimensions the 160-250th, 6th class of precision);

on diameter 76[illegible] (Table 12 for the sizes/dimensions the 60-100th, 5th class of precision;

in diameter 46,5[illegible] (Table 12 for the sizes/dimensions the 40-60th, 6th class of precision taking into account the position, noted on page 117 of p. 4);

on diameter 154[illegible] (Table 12 for the sizes/dimensions the 100-160th, 5th class of precision taking into account the position, noted on page 117 of p. 4);

to the vertical sizes/dimensions:

on height/altitude 41,5[illegible] (Table 10 for the projected area the 160-320th, 6th class of precision);

on height/altitude 33,5[illegible] (Table 10 for the projected area the 160-320th, 6th class of precision);

on the thickness of cross connection 5[illegible] (Table 10 for the projected area the 160-320th, 5th class of precision);

in the depth of indentation $14{,}25^{[illegible]}_{[illegible]}$ (Table 11 for the projected area the 160-320th, 6th class of precision);

in the depth of indentation $20{,}5^{[illegible]}_{[illegible]}$ (Table 10 for the projected area the 160-320th, 6th class of precision taking into account position, noted on page 117 of p. 2);

to the radii of bending and transitions $R8^{[illegible]}_{[illegible]}$ and $R10^{[illegible]}_{[illegible]}$ (Table 14, 5th class of precision);

for the displacement - 0.8 mm (Table 15 for the projected area the 160-320th, 5th class of precision);

for the warping/buckling - 0.6 mm (Table 16 for the sizes/dimensions the 160-250th, 5th class of precision);

to drafts - 5°±1° (Table 17, 5th class of precision);

to the remainder/residue of flash - 1.5 mm (Table 19 for the sizes/dimensions the 160-250th, 5th class of precision).

Example 2. Fig. 16 gives the drawing of the machined rocker from the aluminum alloy AK6 (AMTU 262-55). Machining allowance is assigned 2.25 mm to the side (according to Table 9 for the aluminum alloys

with the purity/finish of the working ∇ 6 and largest overall dimension ∾ 173 mm).

Fig. 17 gives the drawing of the stamped/die-forged blank for the same part.

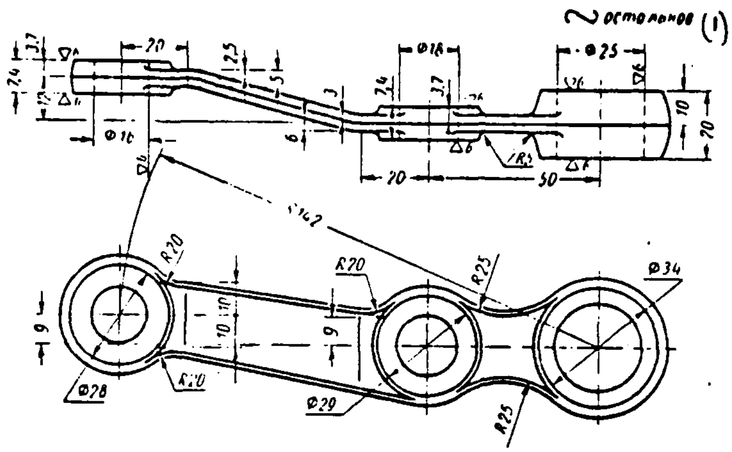

Fig. 16. Drawing of the machined rocker.

Key: (1). remaining.

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Are assigned the following tolerances:

for the horizontal sizes/dimensions:

on diameters 34[illegible], 29[illegible], 28[illegible] (Table 12 for the sizes/dimensions the 25-40th, 5th class of precision);

on the width of part 20[illegible] (Table 12 for the sizes/dimensions the 16-25th, 6th class of precision);

on the width of part $9^{+0.[illegible]}_{-0.[illegible]}$ (Table 12 for the sizes/dimensions the 16-25,6th class of precision taking into account the position, noted on page 117, p. 5);

on profile of part $20^{+0.[illegible]}_{-0.[illegible]}$ (Table 12 for the sizes/dimensions the 25-40th, 5th class of precision taking into account the position, noted on page 117, p. 5);

on the distance between centers 9±0.1 (Table 13 for the sizes/dimensions to the 16th, 5th class of precision);

on the distance between centers 50±0.2 (Table 13 for the sizes/dimensions the 40-60th, 5th class of precision);

on the distance between centers 142±0.4 (Table 13 for the sizes/dimensions the 100-160th, 5th class of precision);

on diameter $20,5^{+0.[illegible]}_{-0.[illegible]}$ (Table 12 for the sizes/dimensions the 16-25th, 6th class of precision taking into account the position, noted on page 117 of p. 4);

to the vertical sizes/dimensions;

on height/altitude 24,5 [illegible], 11,0 [illegible] (Table 10 for the projected area the 25-40th, 6th class of precision);

on height/altitude 6 [illegible] (Table 10 for the projected area the 25-40th, 5th class of precision);

along the profile/airfoil of part 12,5 [illegible] (Table 11 for the projected area the 25-40th, 5th class of precision);

in the depth of indentation 8,5 [illegible] (Table 10 for the projected area the 25-40th, 6th class of precision taking into account the position, noted on page 117 of p. 2);

to the radii of bending and transitions/transfers:
R5 [illegible]; R20 [illegible]; R25 [illegible] (Table 14, 4th class of precision);

for the displacement - 0.4 mm (Table 15 for the projected area the 25-40th, 5th class of precision);

for the warping/buckling - 0.6 mm (Table 16 for the sizes/dimensions the 160-250th, 5th class of precision);

to drafts of -5°±1° (Table 17, 5th class of precision);

to the remainder/residue of flash - 1.0 mm (Table 19 for the sizes/dimensions the 160-250th, 4th class of precision.

Determination of required force for the stamping.

The weight of the falling/incident parts of the stamping double-acting hammer; for the stamped/die-forged blanks circular cross-section, can be determined according to the following formula:

$$G_н = k\,(1 - 0{,}005 D_n)\left(1{,}1 + \frac{2}{D_n}\right)^2 \times$$
$$\times\,(0{,}75 + 0{,}001 D_n^2)\, D_n \sigma_{bt}.$$

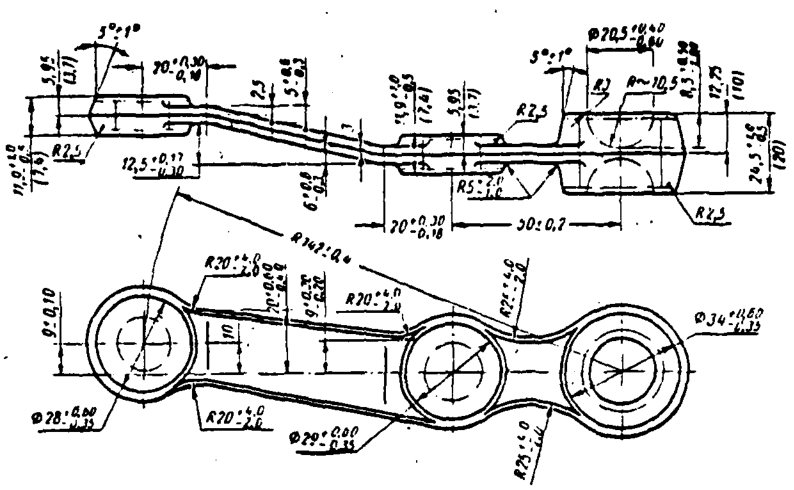

Fig. 17. Drawing of blank for the rockers.

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For the stamped/die-forged blanks of noncircular ones in the plan/layout - according to the formula:

$$G_n = k\,(1 - 0{,}005 D_{np})\left(1{,}1 + \frac{2}{D_{np}}\right)^2 \times \times (0{,}75 + 0{,}001 D_{np}^2) \times \times \left(1 + 0{,}1\sqrt{\frac{L_n}{B_{ncp}}}\right) D_{np}\sigma_{bt}.$$

where G_n - nominal weight of the falling/incident parts of the stamping double-acting hammer in kg; D_n - diameter circular cross-section stamped/die-forged blank in cm; $D_{np} = 1{,}13\sqrt{F_n}$ - the normalized diameter of noncircular in the plan/layout stamped/die-forged blank in cm; $B_{ncp} = \frac{F_n}{L_n}$ - average/mean width of

noncircular in the plan/layout stamped/die-forged blank in cm; F_n - area of noncircular in the plan/layout stamped/die-forged blank in cm²; L_n - length of noncircular in the plan/layout stamped/die-forged blank in cm; σ_{bt} -the limit of the strength of the material to be stamped at a temperature of the end of the stamping in kgf/cm² (Table 20); k - coefficient, which considers the properties of the material to be stamped. for the aluminum, magnesium and copper alloys k=10-15; for the titanium ones - k=12-18. The greatest value k is accepted for greatest values σ_{bt}.

All of the falling/incident parts of the swaging hammer of simple action is determined from the formula

$$G_{\kappa n} = (1{,}5 \div 1{,}8)\, G_{\kappa}$$

The effort/force of hot-stamping crank press for the stamped/die-forged blanks circular cross-section can be determined according to the formula

$$P = 8(1 - 0{,}001 D_n)\left(1{,}1 + \frac{20}{D_n}\right)^2 F_n \sigma_{bt}.$$

For the stamped/die-forged blanks of noncircular ones in the plan/layout - according to the formula

$$P = 8(1 - 0{,}001 D_{np})\left(1{,}1 + \frac{20}{D_{np}}\right)^2 \times \\ \times \left(1 + 0{,}1 \sqrt{\frac{L_n}{B_{n\,cp}}}\right) F_n \sigma_{bt}$$

(comprising formulas the same as for determining the weight of the falling/incident parts of the swaging hammers).

The effort/force of hydraulic press is determined from the formula

$$P = zmFk,$$

where P - effort/force of hydraulic press in the kgf; z - coefficient, which considers deformation conditions:

Smith forging ... 1.0.

Stamping the blanks of simple configuration ... 1.5.

Stamping the blanks of complex configuration ... 1.8.

Stamping the blanks of very complex configuration with the sharp transitions between the sections/cuts; stamping blanks with the large waste metal in the flash; stamping blanks in the presence in metal of the cavities, filled with outflow ... 2.0.

m - coefficient, which considers the effect of the volume being deformed:

(1) Объем штампуемой заготовки в $см^3$				m
(2) До 25				1,0
(3) Св.	25	до	100	1,0–0,9
»	100	»	1 000	0,9–0,8
»	1 000	»	5 000	0,8–0,7
»	5 000	»	10 000	0,7–0,6 ✓
»	10 000	»	15 000	0,6–0,5
»	15 000	»	25 000	0,5–0,4
(3) Св. 25 000				0,4

Key: (1). Volume of the blank to be stamped, in cm². (2). to. (3). above.

F - projected area of the blank (without taking into account flash) to be stamped on the plane, perpendicular to the direction of deforming force, in cm²; k - specific pressure in kgf/cm², that corresponds to the final conditions for the deformation: for the stamped/die-forged blanks with the thin and wide fabrics of the aluminum, magnesium and copper alloys k=5000, of titanium alloys k=6000; for other stampings from the aluminum, magnesium and copper alloys k=3000, from titanium alloys k=5000.

20. Limit of strength of some alloys at temperature of end of stamping.

(1) Марка сплава	(2) σ_{bt} в кГ/мм²	(1) Марка сплава	(2) σ_{bt} в кГ/мм²
АМц, АД1	4	Д1 Д20	10–12 9–10
АМг, АМг3	7–8	Д21 Д16	16–18 14
АМг5В	10–11	МА2	5
АМг3, АМг7	13–15	МА3	12
АВ	6–7	ВМ65-1, ВМ17	6
АК2, АК4, АК4-1	7.5–9.0	Бр АЖН 9-4 Бр Б2	4 5
АК6	8–9	ВТ1, ВТ3	7.5
АК8, ВД17	12–14	ВТ3-1, ВТ4	
В95 В95-1	7.5–8.5 7–8	ВТ5, ВТ8	10

Key: (1). Brand/mark of alloy. (2). in kg/mm².

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The force of friction press can be determined according to the formula

$$P = 2k\sigma_{bt}F,$$

where P - effort/force of friction press in the kgf; k - coefficient, which considers the conditions for deformation (rate, etc.). For the friction presses k=5; σ_{bt} - ultimate strength at a temperature of the end of the stamping in kgf/cm^2. F - projected area of the stamped/die-forged blank on the parting plane in cm^2.

Elements of the construction/design of dies/stamps.

The drawing of the stamped/die-forged blank is the source document for planning the forging dies. Dies/stamps for the alloys of nonferrous metals in practice in no way differ from the dies/stamps, used for stamping structural steel. They can be made on the cubes and on the insets. Such structural elements/cells of dies/stamps as setting places, guides (locks and column), adjusting angle plates, holes for the transportation remain the same as for steel. Exception

are barb grooves, indentations for tonghold, etc., which for the aluminum and magnesium alloys have its specific special features/peculiarities.

Shrinkage for the stamped/die-forged blanks of the aluminum alloys under the condition of heating die/stamp in the process of work on 300-350°C composes 0.8%, at a temperature of die/stamp of lower than 250°C shrinkage must be not lower than 1%.

For the magnesium alloys the shrinkage composes 0.7-0.8% during heating of dies/stamps on 250-300°C. For titanium alloys at an optimum temperature of heating dies/stamps (300-400°C) the average value of shrinkage varies in limits of 0.6-0.7%. for the copper alloys the shrinkage can oscillate in limits of 1.2-1.5%.

Barb grooves. In the dies/stamps for the blanks of the aluminum and magnesium alloys the thickness 2a of barb bridge and a radius of coupling r the wall of cavity from barb bridge are obtained satisfaction considerably greater (approximately/exemplarily to 30%) than for steel. The nonperformance of this condition can lead to the cracks along the parting line of the stamped/die-forged blanks, which are developed after trimming of flash (beyond repair).

Tables 21-23 give the sizes/dimensions of barb grooves for the

varied conditions of stamping the blanks of the aluminum, magnesium alloys and different stamping equipment. For stamping the blanks of copper and titanium alloys of value a, l and r, it is necessary to decrease by 30%.

Indentations for the tonghold. Flash forming during the stamping is inclined to the cracking and the department/separation from the body of stamping. The open indentations for the tonghold present great danger in this respect, whence can escape the piece of flash and traumatize the people located hereabout. In connection with the use/application for stamping the alloys of the nonferrous metals of predominantly single-pass forging dies there is no need for the op tongholds; therefore they make them by those closed (Fig. 18).

Finish of the surface of the die cavity. In connection with the fact that the aluminum and magnesium alloys are stamped at comparatively low temperatures and with the smaller than for steel, stamping drafts/gradients the removal/distance of stamping from the die cavity with the common purity/finish of working is difficult; therefore the die cavity must be manufactured with the purity/finish ∇9, which is reached by polishing.

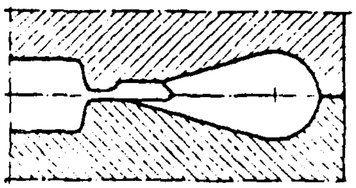

Fig. 18. Coverage of indentation for the tonghold.

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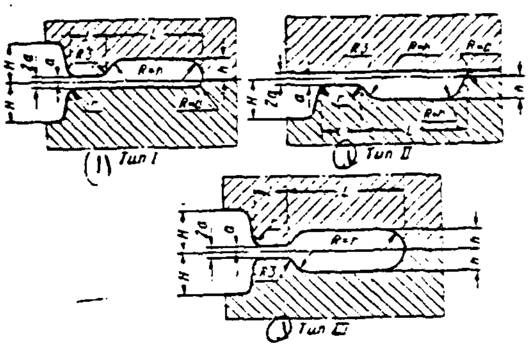
21. Grooves of swaging dies.



(2) Вес падающих частей штамповочного молота в т	2a	h	l (4) при осадке	l (5) при выдавливании	L	(3) Глубина ручья H (6) До 20	(7) Св. 20 (6) до 40	(7) Св. 40
(6) До 1	2.0	5	8	10	30	1.5	2.0	3.0
(7) Св. 1 (6) до 2	3.0	6	10	12	35	2.0	2.5	3.5
» 2 » 4	4.5	8	12	15	45	2.5	3.0	4.0
» 4 » 6.3	6.0	10	15	18	50	3.0	3.5	4.5
» 6.3 » 10	8.0	12	16	22	55	4.0	4.5	5.5

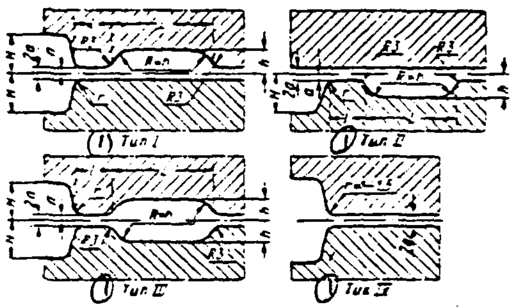
Note. Type I is applied during the stamping with the normal flash;

type II is applied during the arrangement of the die cavity in one lower die (upper die smooth);

type III is applied during the stamping with the large excess of metal.

Key: (1). Type. (2). Weight of falling/incident parts of swaging hammer in m. (3). Depth of groove H. (4). with sediment. (5). with extrusion. (6). To. (7). above.

22. Flash pans of dies/stamps to crank hot die-forged presses.



(2) Усилие пресса Т	(3) Типы I, II, III							(1) Тип IV
	2a	l		h	Глубина ручья H			2a
		(4) при осадке	(5) при выдавливании		(6) До 20	(7) Св. 20 (6) до 40	Св. 40 (7)	
630	2.0	6.0	8.0	5.0	1.5	2.0	2.5	1.5
1000				6.0	2.0	2.5	3.0	
1600	3.0	7.0	9.0		2.5	3.0	3.5	2.0
2000	3.5			8.0	2.5			
2500	4.0	8.0	10.0		3.0	3.5	4.0	2.5
4000	5.0	10.0	12.0	10.0	3.5	4.0	4.5	3.0
6300	6.0	12.0	14.0	12.0	4.0	4.5	5.0	3.5

The note: Size/dimension L is designated at not less than 40 mm, type IV is applied for the calibration operations; types I, II and III are applied in the same cases, as for the swaging dies.

Key: (1). Type. (2). Effort/force of press T. (3). Types. (4). with sediment. (5). with extrusion. (6). To. (7). Higher than.

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For facilitating obtaining the prescribed/assigned purity/finish the

heat treatment of dies/stamps for the aluminum and magnesium alloys is performed by a somewhat greater hardness. For stamping of copper alloys, the die cavity is made as for steel. Purity/finish of working the die cavity for titanium alloys ∇9.

Stamping in the horizontal forging machines.

Aluminum and titanium alloys are stamped mainly in the horizontal forging machines.

Rules of the calculation of the transitions of upsetting. The maximum length of rod, which can be upset for one course of machi... without the defects/flaws, depends on the diameter of the upset rod and is determined by the coefficient of the upsetting

$$k_0 = \frac{L_0}{d},$$

where L_0 - length of the upset part; d - diameter of initial blank.

With the upsetting of aluminum and titanium alloys it is necessary to observe the following relationships/ratios of lengths and diameters of blanks.

Relationships/ratios of lengths and diameters of the blanks:

with the upsetting of blanks with the even/plane end/face, i...

the matrix/die, without the limitation of broadening (Fig. 19a):

d in mm	≥50	30–50	≤30
$k_e \leq 2$		$\leq 1,8$	$\leq 1,6$;

with the upsetting of blanks with the rough draft under the piercing or with the unequal end/face (Fig. 19b)

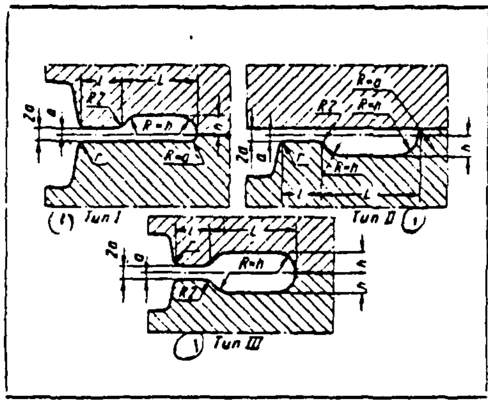
d in mm	≥50	30–50	≤30
$k_e \leq 1,8$		$\leq 1,6$	$\leq 1,3$.

The degree of deformation for one transition must not exceed 50%:

with the upsetting in the male die/punch (Fig. 20a) of the rods with a diameter of

		d_n	D_n	h	k_e
higher than	30 мм:	1,05d	1,3d	1,2d	≤4
to	30 мм:	1,05d	1,2d	1,2d	≤3

23. Grooves of dies to friction presses.



Усилие пресса в т (2)	2s	l при осадке (3)	l при выдавливании (4)	L	h	r
160	1,2	5	6	25	4	1,5
250	1,5	8	8	30		2
400	2,0	8	10	35	5	2,5

Note. Types I, II and III are applied in the same cases, as for the swaging dies.

Key: (1). Type. (2). Force of press in m. (3). with sediment. (4). with extrusion.

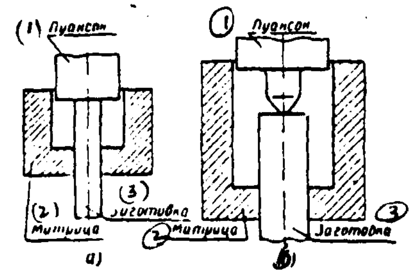


Fig. 19. Upsetting of blanks in matrix/die without limitation of broadening.

Key: (1). Male die/punch. (2). Matrix/die. (3). Blank.

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The calculation of the second and following of transitions is performed on the mean diameter of the truncated cone of the preceding/previous transition, adhering to the recommended relationships/ratios for the first operation of upsetting in the male die/punch (Fig. 20b): $d_n' = 1{,}05\, d_n;\ D_n' = 0{,}6 \times (D_n + d_n);$

with the upsetting in the matrix/die with the limitation of broadening and without limitation of length $l_в$ of the upset part it is necessary to adhere to the following relationships/ratios (Fig. 21):

$$d > 30\ мм,\quad D_ж \leqslant 1{,}2;$$
$$d \leqslant 30\ мм,\quad D_ж \leqslant 1{,}15.$$

Basic concepts of piercing. Diagram 1 (Fig. 22) - cavity is formed in essence due to the distribution of metal to the sides. The cross-sectional area of initial blank is equal to the area of cross section of the pierced part. In the 1st operation by upsetting in the matrix/die is gathered the collar, whose sizes/dimensions correspond to the sizes/dimensions of part. Rough draft under the piercing for the direction of piercing mandrel sometimes simultaneously from the upsetting of collar is obtained satisfactorily. Collar serves for centering the blank in the following groove and eliminating the deformation in the direction of piercing. Depending on the depth of cavity one or several transitions produce piercing into. Upon

penetration of punch the metal is heard to the sides, forming cavity. With the piercing considerable tensile stresses in the pierced part of the blank after penetration of punch of deeper than the height/altitude of collar appear. The fact indicated creates the adverse conditions for the deformation of low-plasticity aluminum alloys.

Diagram 2 (Fig. 23) - piercing with counterflow of metal (reverse/inverse extrusion/pressing). The diameter of initial blank is selected equal to the diameter of part. Piercing occurs under the conditions for nonuniform cubic compression; therefore it is possible to apply it for obtaining the cavity in the blanks of the low-plas .c metals. The effort/force of piercing according to this diagram is considerably more than according to diagram with the distribution of metal. The depth of piercing in this case is limited to the value of course and to the graph of the efforts/forces of machine.

Diagram 3 (Fig. 24) - piercing unites in itself the elements of the deformation of diagrams 1 and 2. In the first operation on the end/face of blank is upset the collar, whose diameter is equal to the diameter of part, and its height h=0.3D.

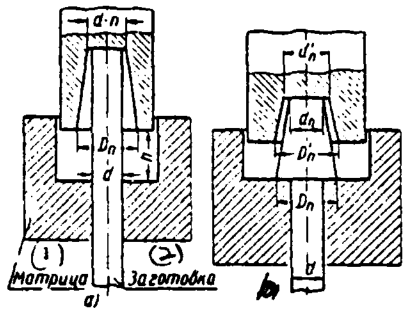


Fig. 20. Upsetting of blanks in the male die/punch.

Key: (1). Matrix/die. (2). Blank.

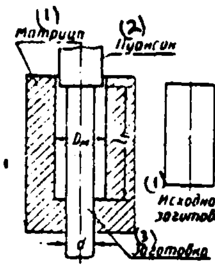


Fig. 21.

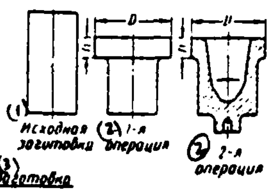


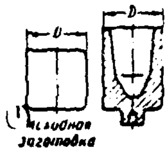
Fig. 22.

Fig. 21. upsetting of blanks in matrix/die with limitation of broadening.

Key: (1). Matrix/die. (2). Male die/punch. (3). Blank.

Fig. 22. Diagram of piercing due to distribution of metal to sides.

Key: (1). Initial blank. (2). operation.



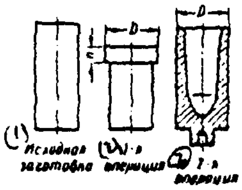


Fig. 23. Fig. 24.

Fig. 23. Diagram of piercing with counterflow of metal.

Key: (1). Initial blank.

Fig. 24. Diagram of piercing with preliminary upsetting of collar.

Key: (1). Initial blank. (2). operation.

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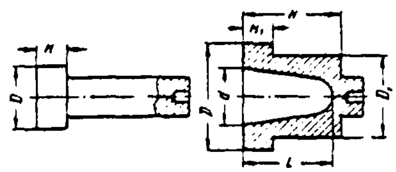
Collar serves only for the centering of blank in the piercing groove. Piercing is produced with male die/punch with the spherical or conical end. In the initial period of piercing simultaneously with penetration of punch into the metal, there occurs upsetting of the blank, since collar in this case does not hold blank, but only it serves for its centering. Penetration of punch into the material is accompanied by upsetting until the compressive stresses caused by the punch become less than resisting of the unpierced/unbroached part of the blank. The distribution of blank to the sides with the metal flow towards the male die/punch in the final period of piercing occurs after this.

Compilation of the drawing of stamping. They develop/process the drawing of stamping on the basis of the drawing of clean/finishing part. To the machined surfaces of part they designate the allowance, whose value is determined according to Table 9 depending on the value of linear dimension and class of the purity/finish of the surface. If the blank is upset on the mount/mandrel, then with the

designation/purpose of allowance for the end/face, which adjoins it, it is necessary to consider the depth of hole in the blank for the approach of the guiding part of the mount/mandrel. After the machining of end/face must not remain the traces of hole. Tolerances in size of stamping designate according to Table 24.

24. Tolerances in size (in mm) of the stampings, manufactured with upsetting in the horizontal forging machines.



(1) H и L	(2) До 50		50—100		100—150		(3) Св 150	
	H	D	H	D	H	D	H	D
(2) До 50	+1,5 −1,0	+1,0 −0,5	+2,0 −1,0	+1,5 −1,0	+2,5 −1,5	+2,0 −1,0	+3,0 −2,0	+2,5 −1,5
Св. 50 до 100	+2,0 −1,0	+1,5 −1,0	+2,5 −1,5	+2,0 −1,0	+3,0 −2,0	+2,3 −1,5	+3,3 −2,0	+2,7 −1,5
Св. 100 до 150	+2,5 −1,5	+2,0 −1,0	+3,0 −2,0	+2,5 −1,5	+3,3 −2,0	+2,7 −1,5	+3,5 −2,0	+3,0 −2,0
Св. 150	+3,0 −2,0	+2,0 −1,5	+3,3 −2,0	+2,7 −1,5	+3,5 −2,0	+3,0 −2,0	+4,0 −2,5	+3,5 −2,0

Note. For inside measurements tolerance - with the opposite sign.

Key: (1). and. (2). to. (3). above.

25. External drafts on end surfaces of collars.

(1) h или h_1 в мм	(3) До 10	10—16	16—30	30—50	50—70
(2) α в град	1	2	3	5	7

Key: (1). h or h_1 in mm. (2). α in deg. (3). To.

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The permissible distortions of the form of the upset blank (displacement, wall thickness variation, ellipticity, etc.) are the same as for the steel stampings. The value of drafts depends on the relationship/ratio of the sizes/dimensions of separate structural elements/cells and character of their shaping. With the upsetting in the matrix/die of blanks without the collars (Fig. 25a and b) drafts are not given to external surfaces. With the upsetting in the die of blanks with one collar on the middle (Fig. 25c), or with two collars at the ends (Fig. 25d) external drafts/gradients α on the ends/faces of collars designate according to Table 25.

During the shaping in the male die/punch (Fig. 25e) external draft β depends on ratio L/D:

$$L/D = 0{,}3 \div 2{,}2, \quad \beta = 15' \div 30';$$
$$L/D = 2{,}2 \div 4{,}2, \quad \beta = 30' \div 1^\circ.$$

The elements of stamping, obtained by outflow (section A, Fig. 25e), are performed without drafts or with the draft/gradient in 1° with deep cavities.

Angle β can be determined according to the formula

$$\beta = 15\left(\frac{L}{D} - 0,3\right) \text{ min.}$$

If L/D≤0.3, then β=0.

With the piercing of blind holes (Fig. 25f) internal draft γ depends on ratio l/d:

$$\frac{l}{d} = 0,5 \div 2,5, \quad \gamma = 15' \div 30';$$
$$\frac{l}{d} = 2,5 \div 4,5, \quad \gamma = 30' \div 1°.$$

Angle γ can be determined from formula γ=(l/d-0.5) min. If l/d≤0.5, then γ=0.

The radii of bending and junctions (Fig. 26) are determined from the formulas

$$r_1 = 0,2h + 1 \text{ мм};$$
$$r_2 = 0,07\,(d + l) \text{ мм}; \quad r_3 = 0,2d \text{ мм}.$$

Remaining radii are determined depending on the amount of

machining allowance and they usually accept maximally possible ones.

Determination of the effort/force of upsetting. The required effort/force P of upsetting is determined on the effort/force, necessary for the deformation in the final groove:

$$P = 5\,(1 - 0{,}001 D_n)\, D_n^2 \sigma \quad (1)\ \text{(без учета заусенца);}$$

$$P = 5\,(1 - 0{,}001 D_n)\,(D_n + 10)^2 \sigma \quad (2)\ \text{(с учетом заусенца),}$$

Key: (1). without the account for the burr. (2). taking into account projecting edge.

where D_n - diameter of the upset blank; σ - specific resisting to deformation at a temperature of the end of the upsetting.

Design features of dies. The clamping groove of the normal design, accepted for steel, does not provide the required clamp of blank of the aluminum alloys. Its use/application leads to the displacement of metal in the axial direction in the process of upsetting, result of which is the incomplete shaping of stamping.

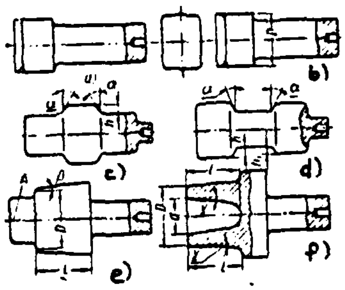

Fig. 25.

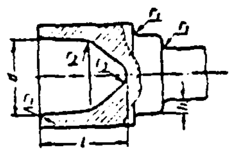

Fig. 26.

Fig. 25. Designation/purpose of drafts to blanks, obtained by upsetting.

Fig. 26. Radii of bending of junctions.

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Grooves in the clamping part of the groove for an increase of the intensity of clamp in this case are not applied, since on the subsequent junctions they lead to the formation of clamps and folds on the clamped part of the blank. To avoid slipping of blank in the axial direction besides the clamping part of the groove, is applied the detent in tongs (Fig. 27a) or into the wa]' of die with the use of special mount/mandrel (Fig. 27b).

For the case of stamping with the detent of blank in tongs the length of the clamping part of the groove they take: with $d_{зае} > 60$ mm, as equal to $L_{з.р} = 3d_{зае}$; with $d_{зае} < 60$ mm, equal to $L_{з.р} = 4d_{зае}$. In this case the part of the blank with a length of l=0.5 $d_{зар}$, but is not less than 30 mm, it must it is located in the clamping part of the tongs (see Fig. 27a).

The structural elements/cells of mount/mandrel and indentation in the matrix/die and the initial, upset blank following: the diameter of mount/mandrel $d_0 = 6 \div 10$ mm; the diameter of the corresponding hole in matrix/die $d_м = d_0 + (2 \div 4)$ mm; the length of the end of the mount/mandrel, which envelopes in blank $l_0 = (1{,}5 \div 2{,}0)\ d_0$; draft/gradient at length l_0 it is equal to 3°; the length of hole in blank $l_з = l_0 + (2 \div 3)$ mm. Mount/mandrel performs with bearing flange $D_0 = 25 \div 30$ mm; the diameter of hole in the die under the flange of mount/mandrel $D_м = D_0 + (4 \div 5)$ mm.

Material for the dies/stamps and the insets, and also the modes/conditions of the heat treatment of dies/stamps and norm of hardness after heat treatment are the same as for the steel stampings (GOST [ГОСТ - All-Union State Standard] 5950-63). This also relates to the tol-rances for the manufacture of the die cavities and the purity/finish of processing.

CALIBRATION.

Mechanism of cold strain during the calibration. The process of cold strain during the calibration, as in other cases, it is accompanied by the strain/work hardening (work hardening/peening) metal, which leads to a change in mechanical properties and thereby, in larger measure, the higher the degree of strain.

The character of a change in the mechanical properties after cold strain for the aluminum alloy AK6 is given in Fig. 28, from which evidently that with an increase in the degree of strain are raised the strength indices (ultimate strength, viscosity/yield and hardness) and descend plasticity indices (elongation, contraction and impact toughness).

Aluminum alloys are less sensitive to the work hardening/peening than steel. Work hardening/peening as a result of cold deformation is utilized for an increase in strength of parts.

The comparison of the mechanical properties of the specimens made from aluminum alloy AK6, cut out from the nondeformed hardened/tempered blanks, with the properties of the samples/specimens of blanks, deformed in the freshly hardened state[1], and of the blanks, deformed in the annealed state and after this

subjected to hardening, they showed that the limit of the strength of longitudinal and transverse samples/specimens from the blanks, deformed in the annealed state, and also impact toughness are not distinguished from the strength and the impact toughness of specimens from the nondeformed blanks.

FOOTNOTE [1]. The strengthened aluminum alloys for 2-4 h after hardening possess high plasticity and can be worked by deformation. State for 2 h after hardening is called freshly hardened. ENDFOOTNOTE.

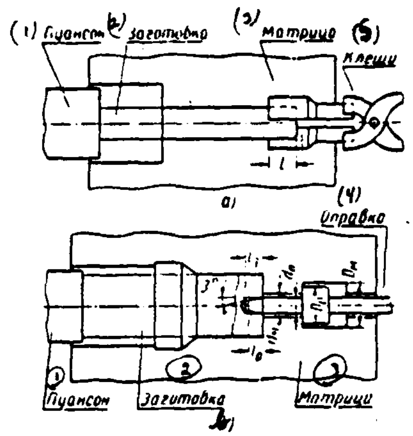

Fig. 27. Schematics of the detent of blanks with the upsetting.

Key: (1). Male die/punch. (2). Blank. (3). Matrix/die. (4). Mandrel. (5). Tongs.

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Elongation per unit length and relative reduction of area in the samples/specimens, deformed in the annealed state, to 30-50% are more than in those not deformed. In the blanks, deformed in the freshly hardened state, ultimate strength, mainly in longitudinal specimens is raised by 2-3%, at the same time to 20-30% descend impact toughness, elongation per unit length and contraction.

Since the plasticity has a great effect on the efficiency of the

machine parts, subjected to alternating loads, the use/application of calibration of aluminum alloys in the freshly hardened state due to a reduction/descent in the plasticity is inexpedient. Therefore one should produce the calibration of alloy AK6, either in the annealed state (since in this case are raised the characteristics of plasticity) or after hot die forging, if the degree of strain is comparatively small.

Hardening after the calibration of the parts of complex configurations leads to their warping/buckling and to the very labor-consuming straightening, while the calibration in the freshly hardened state retains the precision/accuracy of the sizes/dimensi s of part. A reduction/descent in the plasticity of metal is decreased with a decrease in the degree of strain during the calibration. So for example, during the manufacture of compressor blades of jet engines the degree of strain during the calibration does not exceed 5-6%. This small reduction does not lead to a reduction/descent in the plasticity of parts from the aluminum alloys, calibrated in the freshly hardened state, but it makes it possible to avoid labor-consuming straightening.

In the process of calibration nonuniform strain distribution by the volume of blank occurs.

For decreasing the nonuniformity of strain, if the construction/design of blanks allows, on the surfaces, subjected calibration, one should pit (Fig. 29).

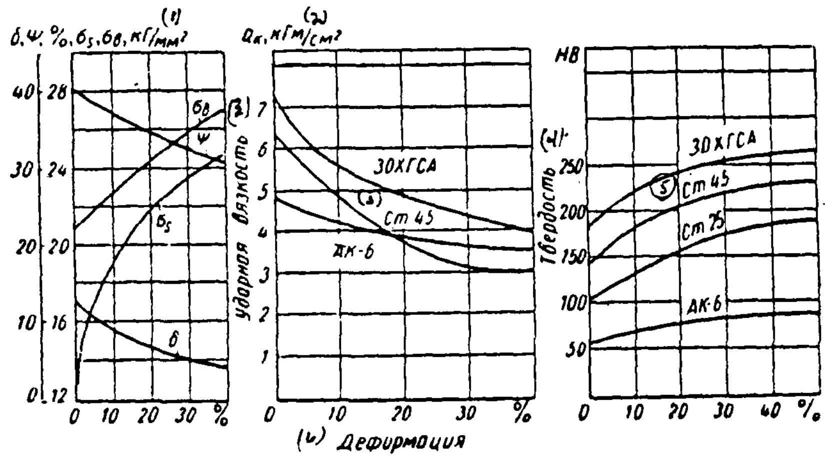

Fig. 28. Mechanical properties of samples/specimens after cold deformation.

Key: (1). kg/mm². (2). kgfm/cm². (3). impact toughness. (4). hardness. (5). cm. (6). Strain.

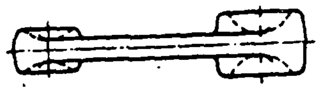

Fig. 29. Indentations in the blanks for decreasing the nonuniformity of strain during the calibration.

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By microstructural analysis, the measurement of hardness and microhardness of individual sections and crystallites of structure established/installed, that the greatest strain/work hardening occurs in the middle part of the volume being deformed and is decreased f n the center to the periphery. Fig. 30 gives the distribution of microhardness over the section/cut of samples/specimens from the aluminum alloy AK6, upset in a cold state with different degree of strain.

Permissible degree of cold strain. The values of accompanying degrees of cold strain (Table 26) are established via the averaging of the degrees of strain, with which begins the decomposition of metal with the reserve of plasticity in 15%.

Special features/peculiarities of strain during the calibration.

The flat surfaces of blank after calibration become convex. Sometimes the convexity reaches several tenths of millimeter. The value of convexity affect the mainly following factors:

the mechanical properties of the material being deformed - the stronger the material, the greater the convexity;

the elastic and mechanical properties of the metal of die/stamp - with an increase in the modulus/module of elasticity and hardness of the metal of die/stamp convexity is decreased;

the form of blanks - convexity increases with an increase in the ratio of the diameter of article to its height/altitude;

the lubrication used and the finish of the surface of the instrument (by use/application of lubrication it is possible to decrease the value of the convexity of ends/faces during the calibration by 30%).

The appearance of convexity on the calibrated flat surface is caused not only by the nonuniformity of normal stresses, which appear as a result of contact friction. The considerable portion of convexity is obtained due to the elastic deflection of die/stamp. According to Ya. M. Okhrimenko the value of the elastic deflection of

die/stamp during the calibration (stamping) is set to known in the theory elasticity to the formula of Busineks (see page 95), according to which the vertical displacements W of points on the surface of elastic half-space (in the case of calibration by sufficiently thick stamp slab) under the action of the external forces of P correspond:

$$W = \frac{P(1-\lambda^2)}{\pi ES}.$$

Different technological procedures (Fig. 31) are applied for decreasing the convexity of ends/faces during the calibration. The precision/accuracy of the calibrated articles can be increased by the use/application of concave ends/faces on the blanks, intended to calibration, and also by the calibration of dies/stamps with the convex working surfaces.

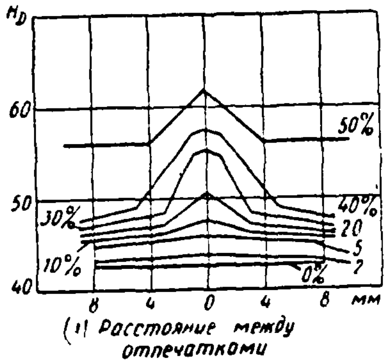

Fig. 30. Distribution of microhardness over the section/cut of samples/specimens.

Key: (1). Distance between the impressions.

26. Permissible degree of cold strain during calibration.

(1) Марка материала	(2) Состояние образцов при деформации					
	(3) без термической обработки			(4) в свежезакаленном состоянии		
	(5) Скорость деформации в м/сек					
	0,01	2	8	0,01	2	8
	(6) Допустимая степень холодной деформации при калибровке в %					
АК8	60	35	25	65	55	45

Key: (1). Brand of material. (2). State of samples/specimens during strain. (3). without heat treatment. (4). in freshly hardened state. (5). Deformation rate in m/s. (6). Permissible degree of cold strain during calibration in %.

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The concavity of the ends/faces of blanks and the convexity of the working surfaces of the slabs of die/stamp are set they experimentally and approximately/exemplarily correspond to the convexity of the ends/faces of blanks in calibratin by flat slabs. V. I. Zalesskiy and A. I. Shtrymov recommend for obtaining the flat surfaces during the calibration the applying of the die/stamp, shown in Fig. 31c. This die/stamp must be designed so that upon reaching/achievement of the maximal load its unsupported part would be deflected to the value of the convexity of ends/faces.

The value of the convexity of ends/faces can be determined according to the empirical formula, proposed R. I. Kazachenok

$$F=\left[0{,}0005\sigma_{e}+\left(\frac{d}{h}-2\right)k_{cp}\right]\left(\frac{d}{20}\right)^{1{,}7},$$

where F - total convexity of two ends/faces; d and h - diameter and the height/altitude of samples/specimens, for which the value of convexity is determined; σ_e - limit of the strength of the material being deformed in kg/mm², k_{cp} - coefficient, depending on the degree of strain ϵ during the calibration:

ϵ	0,05	0,10	0,15
k_{cp}	0,003	0,006	0,008

The tentative value of the convexity of the end/face of samples/specimens with the settling by flat/plane slabs can be also determined according to the empirical formula of L. A. Shofman

$$f = \frac{u}{10^{6}}(k - \sigma_{0,2})\frac{D}{2}\ \text{мм},$$

where u - coefficient, equal to 10-15 for the solid samples/specimens and 5-6 for the annular samples/specimens: k and $\sigma_{0,2}$ - specific pressure and yield point of the material being deformed in kg/mm²; D - outside diameter of sample/specimen in mm.

Requirements for the blanks, subjected calibration. With the small allowance for calibration the required finish of the surface will not be achieved/reached, with the large allowance the precision/accuracy descends and considerably increase the horizontal dimensions of the part of the blank to the subjected calibration.

An increase in the horizontal sizes/dimensions can cause the need for additional machining, furthermore, the large broadening of the calibrated part of the blank can cause the distortion of form and warping/buckling its remaining part, this fact is considered during the development of technological processes and planning of equipment. The sizes/dimensions of the stamped/die-forged blank, perpendicular

to the direction of upsetting, are decreased, so that after the upsetting we obtain required dimensions. Calculation is performed on the basis of the equality of the volumes of the machined part of the stamping before and after calibration and assigned allowance.

For the volumetric calibration they stamp blank with the decreased dimensions in the parting plane, but with those increased along the height/altitude (thickness).

In accordance with the requirements for the precision of the calibrated blanks are established/installed three classes of the precision/accuracy: the calibration of the increased precision/accuracy; normal (common) precision/accuracy; the calibration hot, planar.

Table 27 gives allowances for calibration for different classes of precision/accuracy in the dependence on the area, subjected calibration, and ratios d/h.

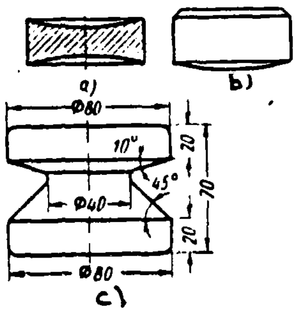

Fig. 31. Technological methods of the decrease of the convexity of ends/faces during the calibration.

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Allowance for calibration is set to Table 27 with the addition to it of half of negative deviation of the appropriate size/dimension before the calibration. Consequently, nominal allowance for the calibration

$$\delta_{\kappa}^{\text{ном}} = \Pi + \frac{b}{2},$$

where Π is the allowance adjusted according to Table 27b - negative deviation of the appropriate size/dimension before the calibration.

Maximum allowance for the calibration

$$\delta_{\kappa}^{\max} = \Pi + \frac{b}{2} + a,$$

where a - positive deviation of the appropriate size/dimension before the calibration.

Minimum allowance for the calibration

$$\delta_{\kappa}^{\min} = \Pi - \frac{b}{2}.$$

Maximum deviations of the sizes/dimensions between the surfaces of the stamped/die-forged blanks, subjected calibration are set to the 4th class of precision according to Table 10.

Values of the fields of tolerances in size between the calibrated surfaces depending on areas subjected to calibration, ratios d_0/h_0 and classes of precision/accuracy are given in Table 28. Depending on the designation/purpose of the calibrated blank the tolerance range can be distributed in a desired manner.

Tolerances for the horizontal sizes/dimensions of the stamped/die-forged blanks, the upsettings perpendicular to direction, and also the tolerances in size, on the thickness, not machined by calibration, are designated just as for the stamped/die-forged blanks, not subjected to calibration. During the determination of allowances and tolerances for calibrating the surfaces of rectangular, elliptical or other form it is necessary to proceed from the area of equivalent wheel/circle.

Before the calibration the stamped/die-forged blanks must be classified into groups with the difference of sizes/dimensions in the thickness within the limits of 0.3 mm. With the high precision/accuracy of calibration the interval is decreased to 0.2 mm or even to 0.1 mm. The readjustment of press is required for calibrating each group, since otherwise it is not possible to obtain the required precision/accuracy of sizes/dimensions.

Stampings with ratio $d_0/h_0 \leq 2$ are calibrated with the necessary precision/accuracy without the classification.

Table 29 gives maximum deviations of the horizontal sizes/dimensions of stampings, obtained after calibration. These deviations are attainable under the condition of decreasing horizontal dimensions before the calibration of the values, given in Table 30.

27. Allowance for calibration in mm.

(1) Площадь, подвергаемая калибровке в см²	d/h (5) До 2: (2) Повышенная	(3) Нормальная	(4) Горячая плоскостная калибровка	(6) Св. 2 до 4: (2) Повышенная	(3) Нормальная	(4) Горячая плоскостная калибровка	(6) Св. 4 до 8: (2) Повышенная	(3) Нормальная	(4) Горячая плоскостная калибровка
(6) До 2,6	0,15	0,25	0,25	0,12	0,20	0,20	0,08	0,12	0,12
(6) Св. 2,6 до 6,0	0,20	0,30	0,30	0.15	0,25	0,25	0,10	0,15	0,15
» 6,0 » 10	0,25	0,35	0,35	0,20	0,30	0,30	0,15	0,25	0,25
» 10 » 18	0,30	0,45	0,45	0,25	0,35	0,35	0,20	0,30	0,30
» 18 » 25	0,35	0,50	0 50	0,30	0,45	0,45	0,25	0,35	0,35
» 25 » 40	0,40	0,80	0,80	0,35	0,50	0,50	0,30	0,45	0,45
» 40 » 80		0,70	0,70		0,60	0,60		0,50	0,50
» 80 » 160			0,80			0,70			0,6
» 160 » 320	—		0,90	—	—	0,80	—	—	0,7
» 320 » 480		—	1,00			0,90			0,8
» 480 » 800			1,2			1,0			1,0

Key: (1). Area, subjected calibration in cm³. (2). Increased. (3). Normal. (4). Hot planar calibration. (5). To. (6). above.

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For the elements of the stamped/die-forged blanks of simple configurations the value of the decrease of horizontal sizes before the calibration can be determined according to the formula of that recommended by S. I. Klyuchnikov

$$z \approx \frac{2F\Delta h}{P(h+\Delta h)},$$

where F - area of the horizontal projection of the calibrated section; P - perimeter of the calibrated section in the horizontal plane; h - thickness of section after calibration; Δh - allowance for

calibration.

Determination of required effort/force for the calibration. The effort/force of press for the planar calibration is determined from the formula

$$P = qF,$$

where q - specific pressure; F - projected area of the part of the blank being deformed to the horizontal plane.

The specific pressure:

for the cylindrical form

$$q = \nu\sigma_{\tau}\left(1 + \frac{\mu}{3}\cdot\frac{d}{h}\right);$$

for the square form

$$q = \nu\sigma_{\tau}\left(1 + \frac{\mu}{3}\cdot\frac{d}{h}\right);$$

for the rectangular form

$$q = \nu\sigma_{\tau}\left(1 + \frac{3b - a}{6b}\mu\frac{b}{h}\right);$$

for the ring

$$q = \nu\sigma_{\tau}\left(1 + \frac{\mu}{3}\cdot\frac{D - d_0}{h}\right),$$

where v - speed factor, equal to 1.4-1.6; σ_{τ} - yield point of

material after calibration, i.e., reinforced by work hardening/peening; μ - coefficient of external friction, equal for Duralumin during the calibration with lubrication 0.06-0.09; d - diameter of blank after calibration; a - side of square or the smaller side of rectangle after calibration; b - large side of rectangle after calibration; D - outside diameter of ring after calibration; d_0 - inside diameter of ring after calibration; h - height/altitude of blank after calibration.

For the small degrees of reduction in ratio $d/h<5$ satisfactory results gives the conditional dependence between q and σ_s:

for upsetting by 5% $q=0.9\ \sigma_s$;

for upsetting by 10% $q=1.1\ \sigma_s$.

28. Field of tolerance in size between the calibrated surfaces in mm.

(1) Площадь, подвергаемая калибровке, в см²	d/h								
	(2) До 2			(3) Св. 2 до 4			(3) Св. 4 до 8		
	(4) Группа точности								
	(5) Повышенная	(6) Нормальная	(7) Горячая плоскостная калибровка	(5) Повышенная	(6) Нормальная	(7) Горячая плоскостная калибровка	(5) Повышенная	(6) Нормальная	(7) Горячая плоскостная калибровка
(2) До 2,8	0,10	0,15	0,20	0,12	0,18	0,25	0,16	0,25	0,30
(3) Св. 2,0 до 6,0	0,12	0,18	0,25	0,15	0,20	0,30	0,20	0,30	0,40
» 6,0 » 10	0,16	0,25	0,30	0,20	0,30	0,40	0,25	0,36	0,45
» 10 » 16	0,20	0,30	0,40	0,25	0,33	0,45	0,30	0,45	0,55
» 16 » 25	0,24	0,35	0,45	0,30	0,45	0,55	0,35	0,50	0,60
» 25 » 40	0,28	0,40	0,55	0,35	0,50	0,60	0,40	0,55	0,70
» 40 » 80		0,45	0,00		0,55	0,70		0,60	0,80
» 80 » 160			0,70			0,80			0,90
» 160 » 320	–	–	0,80	–	–	0,90	–	–	1,00
» 320 » 480			0,90			1,00			1,10
» 480 » 800			1,00			1,10			1,20

Key: (1). Area, subjected calibration, in cm³. (2). To. (3). above. (4). Class of precision/accuracy. (5). Increased. (6). Normal. (7). Hot planar calibration.

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29. Tolerances (in mm) for horizontal sizes/dimensions of elements of stamped/die-forged blanks after calibration.

(1) Площадь, подвергаемая калибровке, в см²	d/h																							
	(2) До 2						(3) Св. 2 до 3						(3) Св 3 до 4						(3) Св 4 до 5					
	(4) Точность размеров между калиброванными поверхностями[1]																							
	П		Н		ГП		П		Н		ГП		П		Н		ГП		П		Н		ГП	
	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н
(2) До 2,5	+0,6	−0,3	+0,8	−0,4	+1,0	−0,5	+0,8	−0,4	+1,0	−0,5	+1,0	−0,5	+1,0	−0,5	+1,2	−0,5	+1,2	+0,6	+1,0	−0,5	+1,2	−0,6	+1,2	−0,6
(3) Св 2,5 до 6,0	+0,8	−0,4	+1,0	−0,5			+1,0	−0,5	+1,2	−0,6	+1,2	−0,6												
» 6,0 » 10					+1,2	−0,6							+1,2	−0,6	+1,5	−0,6	+1,5	−0,8	+1,2	−0,6	+1,5	−0,8	+1,5	−0,8
» 10 » 16	+1,0	−0,5	+1,2	−0,6																				
» 16 » 25							+1,2	−0,6	+1,5	−0,8	+1,5	−0,8							+1,5	−0,8	+1,8	−0,9	+1,8	−0,9
» 25 » 40					+1,5	−0,8							+1,5	−0,8	+1,8	−0,9	+1,8	−0,9						
» 40 » 80	—	—	+1,5	−0,8			—	—	+1,8	−0,9	+1,8	−0,9	—	—					—	—	+2,0	−1,0	+2,0	−1,0
» 80 » 160			—	—					—	—					—	—					—	—		
» 160 » 250					+1,8	−0,9											+2,0	−1,0					+2,2	−1,1
» 250 » 400											+2,0	−1,0												
» 400 » 800					+2,0	−1,0																		

(1) Площадь, подвергаемая калибровке, в см²	d/h																	
	(3) Св 5 до 6						(3) Св 6 до 7						(3) Св 7 до 8					
	(4) Точность размеров между калиброванными поверхностями[1]																	
	П		Н		ГП		П		Н		ГП		П		Н		ГП	
	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н	в	н
(2) До 2,5	+1,0	−0,5	+1,2	−0,6	+1,2	−0,6	+1,0	−0,5	+1,2	−0,6	+1,2	−0,6	+1,0	−0,5	+1,2	−0,6	+1,2	−0,6
(3) Св 2,5 до 6,0																	+1,5	−0,8
» 6 » 10	+1,2	−0,6	+1,5	−0,8	+1,5	−0,8	+1,2	−0,6	+1,5	−0,8	+1,5	−0,8	+1,2	−0,6	+1,5	−0,8	+1,8	−0,9
» 10 » 16	+1,5	−0,8	+1,8	−0,9	+1,8	−0,9	+1,5	−0,8	+1,8	−0,9	+1,8	−0,9	+1,5	−0,8	+2,0	−1,0	+2,0	−1,0
» 16 » 25									+2,0	−1,0	+2,0	−1,0						
» 25 » 40	+1,8	−0,9	+2,0	−1,0	+2,0	−1,0	+1,8	−0,9			+2,2	−1,1	+1,8	−0,9	+2,0	−1,0	+2,2	−1,1
» 40 » 80	—	—					—	—	+2,4	−1,2	+2,4	−1,2	—	—	+2,4	−1,2	+2,4	−1,2
» 80 » 160			—	—	+2,0	−1,0			—	—					—	—		
» 160 » 250					+2,2	−1,1											+2,8	−1,4
» 250 » 400											+2,8	−1,4						
» 400 » 800					+2,4	−1,2											+3,0	−1,5

Key: (1). Area, subjected calibration, in cm². (2). To. (3). above. (4). Precision/accuracy of sizes/dimensions between calibrated surfaces[1].

FOOTNOTE [1]. П - Increased; Н - Normal, ГП - Hot planar; в - upper; - lower. ENDFOOTNOTE.

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30. Values of decrease of horizontal sizes of elements of stamped/die-forged blanks before calibration in mm.

(1) Площадь, подвергаемая калибровке, в см²	d/h: (2) До 2			(3) Св. 2 до 3			(3) Св. 3 до 4		
	(4) Точность размеров между калиброванными поверхностями[1]								
	П	Н	ГП	П	Н	ГП	П	Н	ГП
(2) До 2,6	0,4	0,5	0,5	0,6	0,8	0,8	0,8	1,0	1,0
(3) Св. 2 до 6	0,5	0,6	0,6						
» 6 » 10				0,8	1,0	1,0	0,9	1,2	1,2
» 10 » 16	0,6	0,8	0,8	0,9	1,2	1,2			
» 16 » 25	0,8	1,0	1,0	1,1	1,4	1,4	1,4	1,8	1,8
» 25 » 40	1,0	1,2	1,2	1,2	1,6	1,6			
» 40 » 80		1,4	1,4		1,8	1,8		2,0	2,0
» 80 » 160			1,5						
» 160 » 320	–	–	1,8	–		2,0	–		2,2
» 320 » 480			2,0			2,2		–	2,4
» 480 » 800			2,2			2,4			2,6

(1) Площадь, подвергаемая калибровке, в см²	d/h: (3) Св. 4 до 5			(3) Св. 5 до 6			(3) Св. 6 до 7			(3) Св. 7 до 8		
	(4) Точность размеров между калиброванными поверхностями[1]											
	П	Н	ГП	П	Н	ГП	П	Н	ГП	П	Н	ГП
(2) До 2,6				0,9	1,2	1,9	0,9	1,2	1,2	1,0	1,2	1,2
(3) Св. 2 до 6	0,9	1,2	1,2								1,4	1,4
» 6 » 10				1,2	1,5	1,5	1,2	1,5	1,5	1,5	2,0	2,0
» 10 » 16	1,2	1,5	1,4	1,8	1,8	1,5	2,0	2,0	2,0	2,0	2,5	2,5
» 16 » 25	1,4	1,8	1,8	1,5	2,0	2,0	1,5			2,3	3,0	3,0
» 25 » 40	1,5	2,0	2,0	1,8	2,2	2,2	1,8	2,4	2,4	2,3	3,2	3,2
» 40 » 80		2,2	2,2		2,4	2,4		2,8	2,8		3,4	
» 80 » 160												3,4
» 160 » 320	–		2,4	–		2,6	–		3,0	–		
» 320 » 480			2,6		–	2,8		–	3,2		–	3,6
» 480 » 800			2,8			3,0			3,4			4,0

Key: (1). Area, subjected calibration, in cm². (2). To. (3). above. (4). Precision/accuracy of sizes/dimensions between calibrated surfaces[1].

FOOTNOTE [1]. П - increased; Н - normal; ГП - hot planar.

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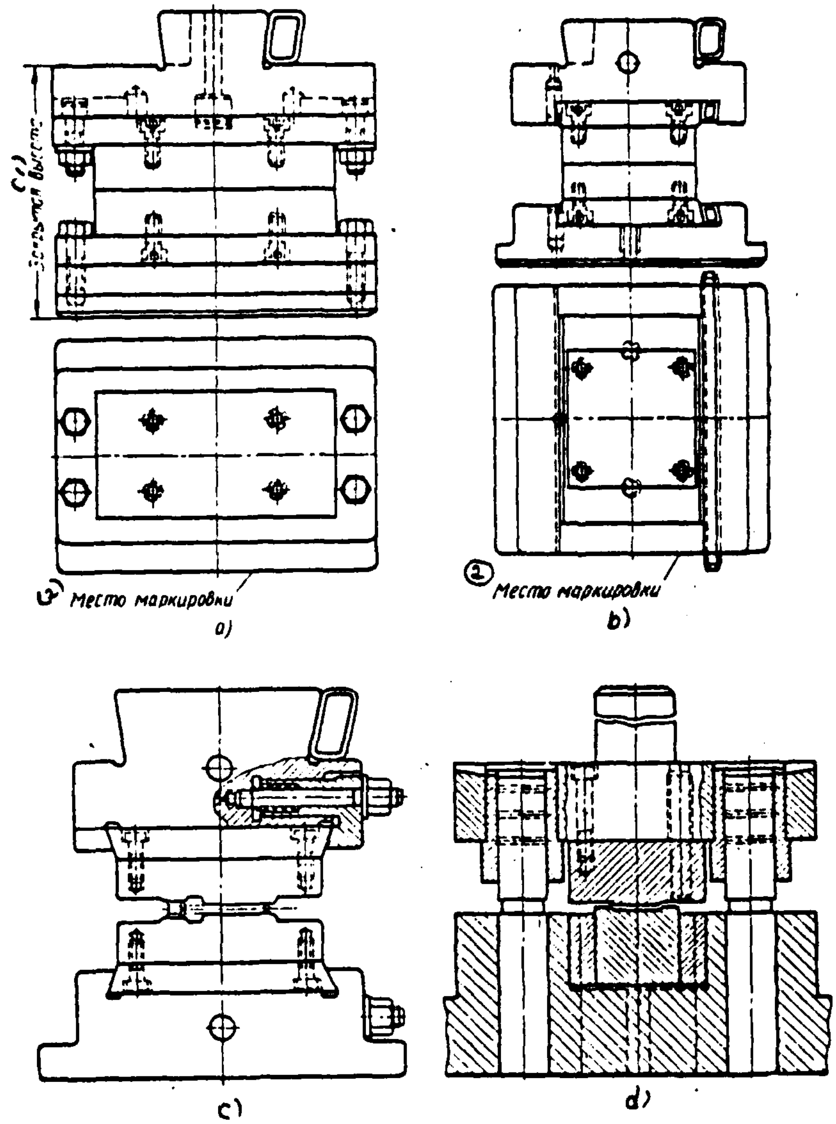

Fig. 32. Examples of constructions/designs of combined dies.

Key: (1). Daylight space. (2). Place of marking.

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Dies/stamps for the calibration and their strengthening block-brackets must be rigid. A quantity of parts in the direction strains must be minimum in order to decrease the strain of die/stamp due to the clearances between the separate parts. The bearing surface of die/stamp must be sufficient so that the surface of a block-bracket would not be deformed.

Die/stamp for the planar calibration (Fig. 32a) consists of upper and lower plates/slabs, upper and lower transfer plates/slabs and block gages. Plates/slabs supporting/reference and transfer are the repeatedly utilized parts of die/stamp, and block gages are manufactured for each concrete/specific/actual part, which must be calibrated.

In the practice are applied other constructions/designs of sizing dies, for example with the the wedge-shaped attachment of the calibration plates/slabs (Fig. 32b) or with the fastening by the special clamp (Fig. 32c). Base plates are manufactured from steel 35 or 45 and thermally work to hardness HB 302-340.

Transfer plates/slabs manufacture from steel 45 and thermally work to hardness HB 364-415. Block gages are made of steel Y10A or X12M and thermally work to hardness HRC 58-60. Dies/stamps for the volumetric calibration are performed with the guide pins (Fig. 32d). Sometimes, with the large bulging out loads, calibration insets are pressed into the special rings (Fig. 32d).

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Chapter 5.

TECHNOLOGY OF FORGING AND STAMPING.

Forms of initial materials.

In connection with the high cost/value of the alloys of nonferrous metals the form and the sizes/dimensions of initial blanks must be maximally approximating forms and sizes/dimensions of stamp ngs, which will make it possible to reduce to a minimum the so-called unavoidable technological losses and mainly the loss of metal to the flash.

The pressed, rolled, forged semi-finished products (Table 1), which are applied in the state after hot deformation, without the heat treatment, serve as initial material for the carrying out of forgings and stampings from the alloys of nonferrous metals. In certain cases during the manufacture of large forgings and stampings (with exception of copper alloys) are applied the casting (ingot) by

weighing from 500 to 4000 kg by diameter respectively from 350 to 850 mm. The ingots before the ductile are tooled. The purity/finish of working must be not below ∇4. Sharp transitions from the channel and sharp/acute faces upon transfer from the lateral surface to the end are not allowed/assumed.

The surface of the rods, utilized for stamping the blanks in particular with the non-machined surfaces, must be turned to the complete removal/distance of defective surface layer. The finish of the surface of the machined/turned blank must be not below ∇5. If defects/flaws remain after machining in the individual sections, them it is necessary to remove by slanting trimming, with the depth of not less than 0.5 mm.

The quality of the surface of the rounds is considerably better than forged ones and pressed. Forged rods are applied for the manufacture: forgings and large-size stampings, if obtaining rods for them pressed or by rolling is difficult.

Forged rods are heterogeneous in the structure and are unstable according to the mechanical properties. Therefore as the initial material they do not satisfy completely the requirements, imposed on the quality of dies.

In order to obtain the high quality of forged semi-finished products, it is necessary to apply the highest degrees of reduction.

A heterogeneous structure of forged rods during the manufacture of them of large critical/heavy-duty forgings and stampings causes crack formation in the metal and large quantity of waste/reject of articles. For manufacturing of forgings and stampings to preferably apply rounds, then pressed and lastly forged. Rounds in comparison with those pressed and forged ones have the best surface and more homogenous structure and mechanical properties.

Form and sizes/dimensions of initial blank must ensure obtaining good-quality stampings with the minimum displacement/movement of metal in the die cavity in the process of shaping. This is especially important for the stampings from the aluminum and magnesium alloys, on surface of which usually are formed the defects/flaws with the complicated displacements/movements of metal in the process of stamping.

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1. Forms of initial materials, used for manufacturing of forgings and stampings from alloys of nonferrous metals.

(1) Сплавы	(2) Пруток			(3) Полоса прессованная	(4) Плита катаная	(5) Слиток
	(6) прессованный	(7) кованый	(8) катаный			
Алюминиевые (9)	(10) Поставляются по ГОСТам 7857—55, 4783—68, 13890—68	(11) Не применяют		—	(12) Поставляются по АМТУ 347—61 толщиной от 12 до 80 *мм* для серийного производства крупных штамповок сложной конфигурации	(13) Для производства крупных поковок и штамповок
(14) Магниевые	(15) Поставляются по АМТУ 516—65 диаметром 8—160 *мм* для серийного производства поковок и штамповок	(11) Не применяют		(16) Поставляются по АМТУ 478—61 сечением до 130 *см*² для серийного производства поковок и штамповок малых и средних размеров	(17) Поставляются по АМТУ 474—61 толщиной от 12 до 80 *мм* для серийного производства крупных штамповок сложной конфигурации	(18) Только при штучном производстве поковок и штамповок
(19) Титановые	(20) Поставляются по АМТУ 487—62 (табл. 3 и 6) Применяются только при разработке и освоении новых сплавов	(21) Поставляются по АМТУ 534—67 (табл. 4 и 6) диаметром 60—250 *мм* для серийного производства поковок и штамповок	(22) Поставляются АМТУ 451—67 (табл. 2 и 5) диаметром до 60 *мм* для серийного производства поковок и штамповок	(11) Не применяют		(23) При производстве крупных поковок
(24) Медные	(11) Не применяют		(25) Поставляются по ГОСТу 1945—59 из меди M1, M2, M3. Прутки латунные по ГОСТу 2060—60. Прутки бронзовые по ГОСТу 1628—60	(11) Не применяют	(26) Поставляются для серийного производства	(11) Не применяют

Key: (1). Alloys. (2). Rod. (3). Band, pressed. (4). Plate/slab, rolled. (5). Ingot. (6). pressed. (7). forged. (8). rolled. (9). Aluminum. (10). They are supplied according to GOST. (11). They do not apply. (12). They are supplied according to AMTU 347-61 with thickness of from 12 to 80 mm for series carrying out of large/coarse stampings of complex configuration. (13). For carrying out of large

forgings and stampings. (14). Magnesium. (15). They are supplied according to AMTU 516-65 with diameter of 8-160 mm for series carrying out of forgings and stampings. (16). They are supplied according to AMTU 478-61 with section/cut of up to 130 cm^2 for series carrying out of forgings and stampings of low and average sizes. (17). They are supplied according to AMTU 474-61 with thickness of from 12 to 30 mm for series carrying out of large/coarse stampings of complex configuration. (18). Only in job work of forgings and stampings. (19). Titanium. (20). They are supplied according to AMTU 487-62 (Tables 3 and 6). They are applied only with development and mastery/adoption of new alloys. (21). They are supplied according to AMTU 534-67 (Tables 4 and 6) with diameter of 60-250 mm for series carrying out of forgings and stampings. (22). AMTU 451-67 (Tables 2 and 5) with diameter of up to 60 mm for series carrying out of forgings and stampings are supplied. (23). In production of large forgings. (24). Copper. (25). They are supplied according to GOST 1945-59 of copper M1, M2, M3. Rods are brass according to GOST 2060-60. Rods are bronze according to GOST 1628-60. (26). They are supplied for series production.

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The volume of blank (Fig. 1) is determined from the formula

$$V_{з} = V_{ш} + V_{об},$$

where $V_{ш}$ – volume of stamping, calculated according to nominal sizes, increased to half of the positive deviations (sizes/dimensions of cavities in the stampings they decrease by half of negative deviations); $V_{об}$ – volume of flash, determined from the formula

$$V_{об} = (S_{м} + kS_{np})\,L,$$

where $S_{м}$ – section/cut of the bridge of flash (Fig. 2); S_{np} – section/cut of the receiver of flash; k - solidity/loading factor of the receiver of flash, depending on the complexity of forging for stampings of the simple configurations k=0.25; the average/mean complexity k=0.50; the complex configurations k=0.75; L - perimeter of the loci of the centers of gravity of the sections/cuts of flash. With a precision/accuracy sufficient for practical purposes, valu. during the production calculations they take as the equal to the perimeter of stamping.

The sizes/dimensions of barb grooves are given in Chapter 4.

Form and sizes/dimensions of initial blank depend on the configuration of stamping.

For the stampings, which have the shape of bodies of revolution and close to them, stamped by upsetting into the end/face, the length of blank they select the equal less than its three diameters, i.e., $l_{з} \leq 3d_{з}$.

The diameter of blank is determined from the formula

$$d_{\text{з}} = 0{,}75\sqrt[3]{V_{\text{з}}}.$$

The majorities of stampings stamp from the blanks "on flatly/planely". For the stampings from the alloys of the nonferrous metals, whose initial blanks are hammered, the section/cut of initial blank is selected only over the greatest section/cut of stamping, i.e.

$$S_{\text{заг}} = S_{\text{шт}}^{\max} + 2(S_{\text{м}} + kS_{\text{пр}}).$$

Length of blank $l_{\text{заг}} = \frac{V_{\text{заг}}}{S_{\text{заг}}}$.

They reshoe the selected initial blank to the necessary form in conformity with the form of stamping. The preliminary preparation for blank for stampings of small width with the thickening at one or both ends should be produced in the horizontal forging machine (set of material for the thickened part of the stamping). In this case the section/cut of initial blank must be selected over the smallest section/cut of stamping.

The preliminary preparation for blank for stampings of those decreasing or simultaneously attenuating and expanding from one that thickened and expanding from one butt end can be produced on the forging rolls. In this case the section/cut of initial blank is

selected over the greatest section/cut of stamping.

Both upsetting in the horizontal forging machine, and rolling are more productive than forging, but the carrying out of stampings from the alloys of nonferrous metals are very sharply applied in the practice.

Cutting measured blanks.

Initial materials from aluminum, magnesium and copper alloys are cut to the blanks on circular saws, slicing-lathe machine tools, mechanical knives and high-speed horizontal milling machines, it . special for this of those fitted out.

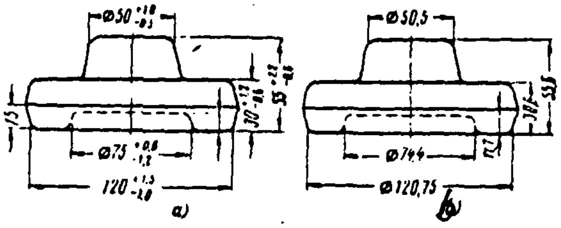

Fig. 1.

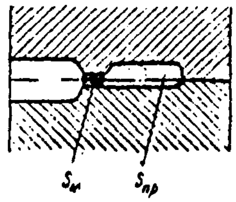

Fig. 2.

Fig. 1. Volume of blanks: a) forging; b) drawing/draft for calculating volume.

Fig. 2. Section/cut of bridge of flash.

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Cutting on the shear press is not allowed/assumed in connection with the possibility of formation in the places of the shear/section of the microcracks, which during further deformation can lead to the considerable defects/flaws.

In the case of forging the blanks, designed for obtaining of several forgings, is expedient the use/application of the subsequent chopping immediately after forging. For the magnesium alloys, besides MA2 and BM65-1, the cutting in the hot state is not recommended. Cutting blanks in the hot state can be applied from the initial

material with a diameter of up to 100 mm with the observance of the thermomechanical modes/conditions of forging. During cutting of blanks the broadening to 10-20% in the direction of cutting at the length of 10-15 mm occurs.

Cutting on circular saws (Table 2 with the speed of rotation of disk 30-35 m/min and with minimum supply provides obtaining blanks with the clean ends/faces. At the speed of rotation of disk it is less than 25 m/min and to minimum supply ends/faces have uneven surface, which with some forms of forging can lead to the formation of cracks. After cutting from the edges of blank are chamfered for the purpose of deburring.

For cutting the blanks of titanium alloys, besides equipment indicated above, anode-mechanical and abrasive machine tools are applied; their cutting on the abrasive machine tools is limited. The diameter of the blank cut must not exceed 60 mm. To the diameter of 20 mm cutting is performed without the cooling lubrication.

Anode-mechanical cutting of blanks of titanium alloys performs both on the disks and on the strip/tape machine tools. The water glass of specific weight/gravity 1.28-1.32 is applied as the working liquid medium.

Cutting titanium blanks on the shear press is performed in the hot state with the heating to the temperatures, given in Table 3, with exception of the alloys BT1-00; BT1-0 and OT4-0, which can be cut in the cold state.

2. Cutting blanks on circular saws during different modes/conditions of cutting.

(1) Диаметр заготовки в мм	(2) Мощность электро-мотора в квт	(3) Диаметр пилы в мм	(4) Толщина режущей части зубцов в мм	(5) Число оборотов диска в минуту	(6) Величина подачи диска в мм за один оборот диска
25	2,2	300	5	16	3,0
25	2,2	300	5	33	1,7
60	2,2	800	5	16	1,3
60	2,2	300	5	33	0,7
80	5,2	500	5	33	0,3

Key: (1). Diameter of blank in mm. (2). Power of electric motor in kW. (3). Diameter of saw in mm. (4). Thickness of cutting edge of teeth in mm. (5). Number of revolutions of disk per minute. (6). Rate of feed of disk in mm in one revolution of disk.

3. Temperature of heating blanks of titanium alloys for cutting on shear press.

(1). Сплав	Температура в °С (2)		(1) Сплав	Температура в °С (2)	
	(3) нагрев не выше	(4) резка не ниже		(3) нагрев не выше	(4) резка не ниже
ОТ4-1	880	750	ВТ8	950	900
ОТ4	900		ВТ9		
ВТ4	920	800	ВТ14	900	750
ОТ4-2	940	850	ВТ15	800	
ВТ5	950	900	ВТ16		
ВТ5-1			ВТ18	980	900
ВТ6С	900	800	ВТ20		
ВТ6	920		ВТ22	820	750
ВТ3-1	930	850			

Key: (1). Alloy. (2). Temperature in °C. (3). heating is not above. (4). cutting is not below.

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Cutting on hammers and presses of the preliminarily deformed blanks is produced only in the hot state and when the blanks must undergo further working by pressure. The data about the temperature of heating the blanks before the cutting are cited in Table 4. Ingots can be cut only at a temperature of the beginning of deformation (Table 5).

Cutting ingots and rods on the lathes is performed by the

cutting-off tools, equipped with the plates of hard alloy BK8.

The geometric parameters of the cutting-off tools:

$\gamma_{\phi} = 0 \div 5^\circ$; $\alpha = 12^\circ$; $\phi_1 = 3^\circ$; $\alpha_1 = 1.5^\circ$; $f = 0.2-0.3$ mm.

4. Temperature of heating deformed blanks of titanium alloys for cutting on hammers and hydraulic presses.

(1) Сплав	(2) Температура в °С: (3) нагрев не выше	(2) Температура в °С: (4) рубка не ниже	(1) Сплав	(2) Температура в °С: (3) нагрев не выше	(2) Температура в °С: (4) рубка не ниже
ВТ1-00 ВТ1-0 ОТ4-0	850	750	ВТ6С ВТ6	950	900
ОТ4-1 ОТ4	900 930	850	ВТ8 ВТ9	1000	950
ОТ4-2	1000	950	ВТ14 ВТ15	900	850 800
ВТ4 ВТ3-1	950	900	ВТ10	850	750
ВТ5 ВТ5-1	1000	950	ВТ18 ВТ20	1000	960
			ВТ22	900	

Key: (1). Alloy. (2). Temperature in °C. (3). heating is not above. (4). cutting is not below.

5. Temperature of heating ingots from titanium alloys for cutting on hammers and hydraulic presses.

(1) Сплав	(2) Температура в °C		(1) Сплав	(2) Температура в °C	
	(3) нагрев не выше	(4) рубка не ниже		(3) нагрев не выше	(4) рубка не ниже
ВТ1-00 ВТ1-0 ОТ4-0 ОТ4-1	1000	950	ВТ6С ВТ6	1050	1000
			ВТ8 ВТ9	1100	1050
ОТ4 ВТ4 ОТ4-2	1020 1050 1100	970 1000 1050	ВТ14 ВТ15 ВТ16	1050 1150 1000	1000 1100 1060
ВТ3-1	1150	1000	ВТ18 ВТ20	1150	1100
ВТ5 ВТ5-1		1100	ВТ22	1000	950

Key: (1). Alloy. (2). Temperature in °C. (3). heating is not above. (4). cutting is not below.

6. Maximum deviations of length of measured blanks during cutting on different equipment.

(1) Оборудование	(2) Диаметр заготовки в мм	(3) Длина заготовки в мм		
		(4) До 150	(5) Св. 150 (4) до 300	(5) Св. 300
		(6) Предельные отклонения в мм		
(7) Пресс-ножницы, молот свободной ковки, гидравлический пресс	(4) До 40 (5) Св. 40 (4) до 80 (5) Св. 80	± 3,0 ± 4,0 ± 5,0	± 4,0 ± 5,0 ± 6,0	± 5,0 ± 6,0 ± 8,0
(8) Дисковая пила, механическая ножовка, анодно-механический станок, абразивный станок	(4) До 40 (5) Св. 40 (4) до 80 (5) Св. 80	± 1,0 ± 1,5 ± 2,0	± 1,5 ± 2,0 ± 2,5	± 2,0 ± 2,5 ± 3,0
(9) Отрезной станок, быстроходный фрезерный станок	(4) До 40 (5) Св. 40 (4) до 80 (5) Св. 80	± 0,5 ± 1,0 ± 1,5	± 1,0 ± 1,5 ± 2,0	± 1,5 ± 2,0 ± 2,5

Key: (1). Equipment. (2). Diameter of blank in mm. (3). Length of blank in mm. (4). To. (5). Above. (6). Maximum deviations in mm. (7). Shear press, hammer for smith forging, hydraulic press. (8). Circular saw, metal sawing machine, anode-mechanical machine tool, abrasive machine tool. (9). Cutting machine, high-speed milling machine.

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Modes/conditions of the cutting: cutting speed v=25-30 m/min; supply to s=0.2-0.3 mm/rev.

The sharp edges of ends/faces in cut-off blanks, if they are intended for the stamping into the end/face or the upsetting on GKM, to avoid clamps, must be rounded in the blanks with a diameter of up

to 50 mm, R=1.5-2 mm and in blanks by diameter are more than 50 mm R=3-4 mm.

The stripping of blanks of titanium alloys is produced by the cutters, equipped with hard alloy BK4 or BK8 with the following geometric parameters: $\gamma_\phi = 0°$; $\alpha = 12°$; $\varphi=45°$; $\varphi_1=45°$; $\lambda=0°$; R=1.5 mm; f=1.5-2 mm. The modes/conditions of the cutting: cutting speed v=15-30 m/min; supply s=0.5-0,8 m/min; the depth of cutting is t=5-10 mm. In this case it is necessary to apply the cutting fluid (5% emulsion according to GOST 1975-53), supplied under the pressure 10-15 atm.

Tolerances for the length of blanks of different materials, obtained during cutting on different equipment are given in Table 6.

Heating blanks.

Heating the blanks before the ductile and the stamping must ensure:

the uniform heating of metal to the prescribed/assigned temperature throughout entire section/cut in the minimum time;

the minimum saturation of the heated metal by gases (hydroge-

oxygen, nitrogen);

the non-admission of cracks due to the sharp temperature drops over the section/cut of the heated metal;

the avoidance of the prolonged processes of recrystallization, and consequently, minimum grain-growth;

a precise accomplishing of the prescribed/assigned mode/conditions of heating on the temperature, the rate and the heating time.

Furnaces for heating of blanks. In all cases, when this is possible, should be preferred furnace with the continuous load, ensuring the specific rhythm productions, and consequently, higher productivity and making it possible to better utilize electric power.

In the small-scale or unit production (large forgings) the possibility of using the continuous furnaces is limited and is necessary to apply the chamber ones of furnace with the intermittent load. In the large-scale and mass production, where after by the determined by production aggregates/units (hammers, presses, forging machines) is fastened a small quantity of same-type parts, successfully are applied the automated furnaces with the continuous load.

The electric heating furnaces of resistance it is expedient to apply for the heating prior to forging and stamping the blanks of small section/cut or intricate shape with the insignificant volume of production, and also in cases when high requirements on the quality of heating (high degree of uniformity of the temperature in the working chamber, the high precision/accuracy of the control of temperature, etc.) are imposed especially.

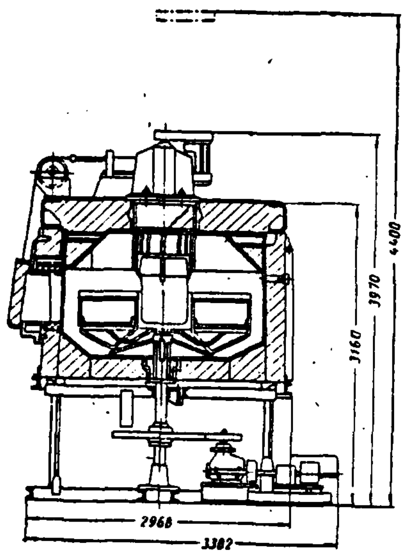

Fig. 3. Electric furnace.

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Resistance furnaces, chamber type with the shielded heating elements, with the forced circulation of air and with the automatic temperature control (Table 7) found the greatest use/application. The possibility of guaranteeing any temperature conditions and the ease/lightness of the automatic control of this mode/conditions are the advantage of these furnaces. During the heating the temperature drop in the blanks, which depends on the heating conditions, occurs: the smallest temperature drops it is possible to achieve in the electric furnaces with the forced circulation of heated air by

powerful/thick fans.

The plants of the electrothermal equipment of the Ministry of Electrical industry manufacture standard installations for heating of measured blanks, in particular revolving type electric furnace CAO-21-11-3/5 test M-02 (Fig. 3), which is the modernization of the previously released electric furnace OKB-494. The advantages of new furnace are the following:

in the furnace is established/installed fan with the best aerodynamic indices and the best efficiency, which provides the more uniform heating of blanks;

the heater of cutting, which improves repairability both furnace itself and heater without the removal/output of cover/cap;

in the drive of rotating mechanism of hearth they are established/installed new reducer and variator, that ensure the reliable and uninterrupted work of mechanism.

Technical characteristic to the electric furnace revolving CAO-21-11-3/5 test M-02, intended for the heat treatment and the heating prior to stamping of blanks of the nonferrous metals and the alloys at a maximum temperature of heating to 500°C.

Power in kW ... 75+10%.

Operating temperature (it is regulated automatically) in °C ... 500.

Number of thermal zones ... 1.

Atmosphere of furnace ... air.

Warmup time to operating temperature in h ... 4.

Weight of blank in kg ... 156.

Specific consumption of electric power in kW·h/kg ... 0.26.

Time of the determination of parts in the furnace in min ... 10-40.

Productivity of furnace in kg/h ... 250.

Sizes/dimensions of working space in mm:

the outside diameter of the rotating hearth ... 2200.

the inside diameter of the rotating hearth ... 880.

height/altitude and the width of discharging window ... 200+230+420.

Speed of rotation of hearth in rev/h ... 6.33.

Total weight of furnace in t ... 9.

7. Fundamental characteristics of electric heating furnaces.

(1) Тип печи	(2) Размер рабочей камеры печи в мм	(3) Мощность в квт	(4) Число зон	(5) Вес одновременно загружаемого металла в кг
ПН-12[1]	460×900	25	1	30—70
ПН-13[1]	600×1300	50		40—100
ПН-15[1]	900×1800	60		80—200
(6) Методическая печь	—	700	5	(7) Непрерывная загрузка 150—300
Печь карусельного типа (8)	⌀ 880	75	1	

Key: (1). Type of furnace. (2). Size/dimension of working chamber of furnace in mm. (3). Power in kW. (4). Number of zones. (5). Weight of simultaneously charged metal in kg. (6). Continuous furnace. (7). Continuous load 150-300. (8). Revolving type furnace.

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[1]. In these furnaces the simultaneous heating of the measured blanks of the larger weight (approximately/exemplarily to 50% more than the weight, indicated in the table), is allowed/assumed; in this case the heating time must be increased to 25%. ENDFOOTNOTE.

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Furnaces are equipped with instruments for the automatic temperature control with the precision/accuracy within limits of ±10°C.

For the measurement of the temperature in the heating zone the

thermocouple is established/installed at a distance of 100-150 mm from the blanks.

Under the furnaces it should not be covered/coated with sheets from the high-temperature (strength) alloys with the content of nickel above 50% , since in this case the sticking of blanks is possible.

The blanks charged into the furnace must be purified from oil, metallic dust, projecting edges and other pollution/contamination. It is necessary strictly to keep track of the fact so that steel blanks would not remain in the furnace and the charged blanks did not come into contact with heating elements.

The blanks of the heated batch must be placed in the furnace so that their uniform warming up (it must be provided free air circulation) would be provided. During the arrangement/position of blanks on the hearth of furnace in one series/row, it is necessary to pack them with certain interval.

Blanks must be charged into the preliminarily heated to the prescribed/assigned temperature furnace (according to the modes/conditions, established/installed for this brand/mark of alloy). When in the furnace blanks were heated at higher temperatures, it is necessary preliminarily to cool to bake lower

than the prescribed/assigned temperature on 50-100°C, then to raise temperature to the prescribed/assigned for this alloy and after 20-30 min holding to produce the load of the blanks of new batch. The blanks with a diameter above 150 mm should be manipulated in every 30 min.

During the manufacture of the parts of critical/heavy-duty designation/purpose (disks, compressor blades, etc.) from titanium alloys with the low allowances, heating blanks prior to the stamping should be produced in the furnaces with prot ctive atmosphere for the purpose of the exception/elimination of the formation of the alpha-deposited layer.

The use/application of a protective medium in the form of technical argon protects from the formation of considerable scale and decreases the value of the alpha-deposited and transition layers (Fig. 4-10). However, technical argon does not create overall protection. The use/application of purified argon is more effective protection.

The use/application of protective coatings in the form of the enamel, which consists of oxides SiO_2, BaO, TiO_2, MgO, Al_2O_3, ZrO_2, CaO, Na_2O_3, B_2O_3, protects from the formation of scale and decreases the value of the alpha-deposited layer. Enamels shield well metal

during the heating to 1000-1050°C.

One should consider that the protective coatings (enamel) react during the heating with metal itself, loosening to it oxygen; therefore the alpha-deposited layer increases with an increase in temperature and heating time. Shielding enamels are simultaneously lubrication.

The permissible retention time of blanks of the alloys of nonferrous metals in the furnace at a forging temperature must correspond to the data, given in Table 8-14.

With forging of ingots from titanium alloys with a diameter of 350-400 mm to the rods or reshoeing of rods to other sizes/dimensions it is necessary to be guided by the data, given in Table 15.

Its temperature, naturally, is depressed after the load of blanks in the furnace heated to the necessary temperature, while it begins slowly to be raised after the termination of load.

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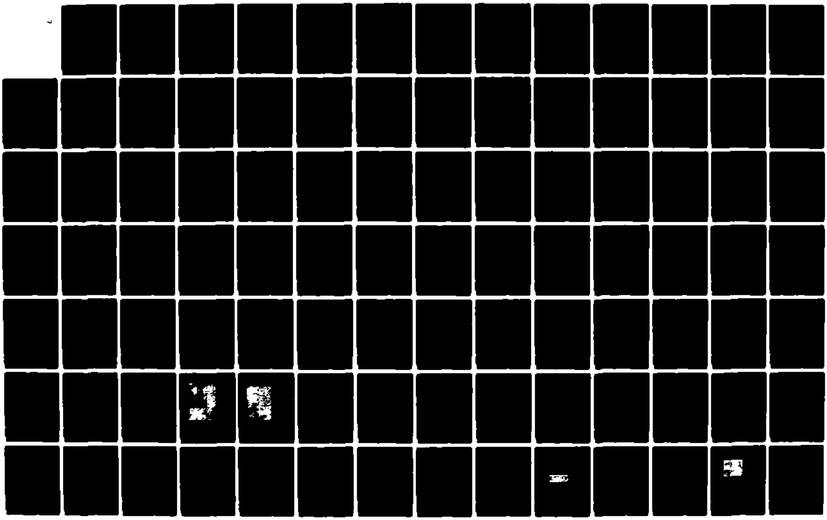

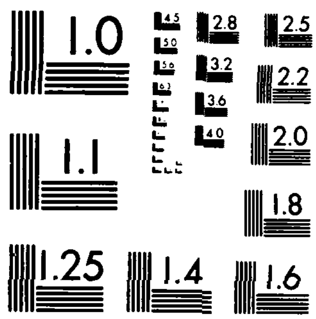

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

8. Time of heating aluminum, magnesium and copper alloys.

(1) Сплавы	(2) Диаметр или толщина заготовки в мм		
	(3) До 50	(4) Св. 50 (3) до 100	(4) Св. 100
	(5) Время (в мин) нагрева 1 мм, диаметра (толщины)		
(6) Алюминиевые и магниевые . .	1,5	$T = 1,5 + 0,01 (d - 50)$	2,0
(7) Медные	0,75	$T = 1,0 + 0,005 (d - 50)$	1,0

Key: (1). Alloys. (2). Diameter or thickness of blank in mm. (3). To. (4).above.(5). Time (in min) of heating 1 mm, diameter (thickness). (6). Aluminum and magnesium. (7). Copper.

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With forced outages with duration to 6-7 h the temperature in the furnace for the blanks of the aluminum alloys must be lowered to 430-470°C, and blanks left in the furnace; with the interruptions of more than 7 h of blank it is necessary to unload from the furnace. During heating of blanks of the magnesium alloys MA3 and MA5 with the interruptions to 4 h, and alloy BM65-1 to 2 h the temperature of furnace must be lowered to the lower limit, established/installed for each of alloys in question, whereas blanks must remain in the furnace; with the interruptions more than 4 h for the alloys MA2, MA3 and MA5 and more than 2 h for the alloy BM65-1 blanks it is necessary to unload from the furnace.

9. Time of heating magnesium alloys.

(1) Сплав	(2) Температура нагрева в °C	(3) Время нагрева в ч	(2) Температура нагрева в °C	(3) Время нагрева в ч
МА3	400	5	450	3
МА8	400	4	420	2
ВМ17	400	3	420	2
ВМ65-1	400	6	450	2

Key: (1). Alloy. (2). Temperature of heating in °C. (3). Heating time in h.

10. Permissible retention time in furnace of preheating blanks of titanium alloys.

(1) Максимальное сечение заготовки в мм	(2) Время нагрева в ч	(1) Максимальное сечение заготовки в мм	(2) Время нагрева в ч
(3) До 50	1,0	(4) Св. 140 (3) до 200	2,5
(4) Св. 50 (3) до 70	1,5	(4) Св. 200 (3) до 250	3,0
(4) Св. 70 (3) до 140	2,0	(4) Св. 250 (3) до 350	4,0

Key: (1). Maximum section/cut of blank in mm. (2). Heating time in h. (3). To. (4). above.

11. Time of heating blanks of titanium alloys to temperature they are ductile.

(1) Толщина или диаметр заготовки в мм	(2) Время нагрева до температуры ковки по показанию самопишущего потенциометра в мин (не более)	(3) Время нагрева при температуре ковки в мин (не менее)
400	50	100
350 300	40	130 120
250 225	35	100 90
200 180	30	80 70
100 140	25	60 55
120 100	20	50 45
80 60 50	15	35 30 25
40 35	13	20
30 25 20	10	15
15 10 (4) и менее	8 5	12 10

Key: (1). Thickness or the diameter of blank in mm. (2). Heating time to forging temperature from reading/indication of recording potentiometer in min (not more). (3). Heating time at forging temperature in min (not less). (4). and less.

12. Maximum permissible retention time in furnace of blanks of titanium alloys.

(1) Толщина или диаметр заготовки в мм	(2) Максимально допустимое время пребывания заготовки в печи при ковочной температуре в мин
400—350	240
350—250	210
250—200	150
200—150	120
150—100	90
100—60	75
60—30	60
30—10	60

Key: (1). Thickness or the diameter of blank in mm. (2). Maximum permissible retention time of blank in furnace at forging temperature in min.

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13. Mode/conditions of heating some copper alloys.

(1) Сплав	(2) Сечение заготовки в мм	(3) Развес в кг	(4) Температура печи в °C	(5) Продолжительность нагрева в печи с температурой °C				(6) Продолжительность выдержки в ч	(7) Общее время нагрева в ч
				700—750	800	850	900		
ЛТ90	d=120	35—50					0,65	0,35	1,0
	250×250 300×300	400 700	900			–	2,5 3,0	0,50	3,0 3,5
Л62	d=120	35—50				0,55		0,35	0,9
	250×250 300×300	400 700		–	–	2,5 3,0		0,50	3,0 3,5
ЛН65-5	d=120	35—50	850			0,5		0,25	0,75
	250×250 300×300	400 700				2,25 2,75	–	0,50	2,75 3,25
	d=400	1400				4,0		0,65	4,05
АЖМц	d=120	35—50			0,5			0,35	0,85
59-1-1	250×250 300×300	400 700	800		2,5 3,0	–		0,50	3,0 3,5
ЛМц58-2	d=120	35—50		0,65				0,35	1,0
	250×250 300×300	400 700	750	2,0 2,5	–			0,50	2,5 3,0

Key: (1). Alloy. (2). Section/cut of blank in mm. (3). Weighing in kg. (4). Temperature of furnace in °C. (5). Heating time in furnace with temperature of °C. (6). Duration of holding in h. (7). Total heating time in h.

14. Heating temperature prior to stamping on GKM.

(1) Сплав	(2) Температура нагрева в °C: (3) оптимальная	(4) не выше	(1) Сплав	(2) Температура нагрева в °C: (3) оптимальная	(4) не выше
BT1-0 BT1-00	850	870	BT6	920	940
OT4-0		880	BT8 BT9	950	970
OT4-1 OT4 BT4 OT4-2 BT3-1	880 900 920 950 930	910 920 950 980 950	BT14 BT15	900 850	930 880
			BT18 BT20	970	980 1000
BT5 BT5-1	970	990	BT22	850	880

Key: (1). Alloy. (2). Temperature of heating in °C. (3). optimum. (4). not above.

15. Examples of modes/conditions of heating blanks of titanium alloys for forging to rods and reshoeing of rods.

(1) Диаметр заготовки в мм: (4) начальный	(5) конечный	(2) Время нагрева в мин	(3) Температура нагрева в °C по маркам сплавов: BT3-1	BT6, BT14	BT5	BT4, BT8
350	200	120	1050		1150	1100
200 120	120 100	90 60	960	940	1030 980	980

Key: (1). Diameter of blank in mm. (2). Heating time in min. (3). Temperature of heating in °C on brands/marks of alloys. (4). initial. (5). final.

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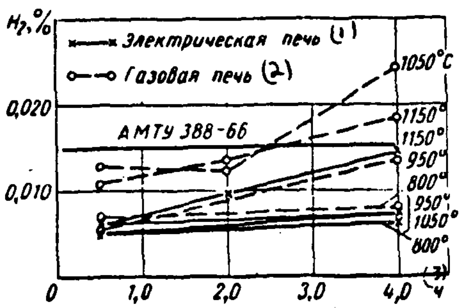


Fig. 4.

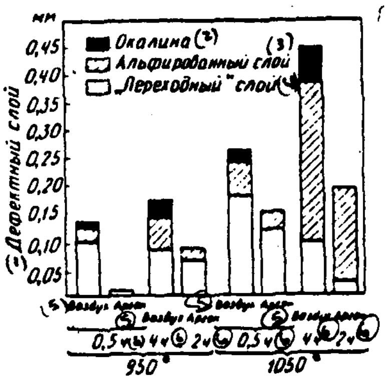


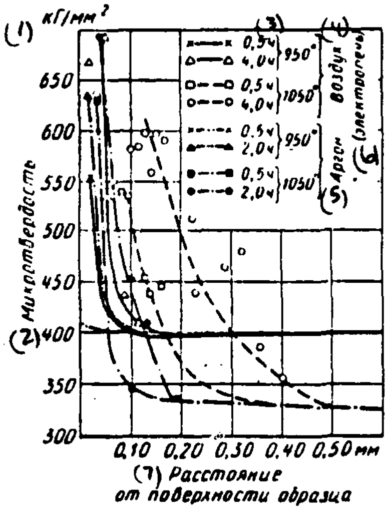
Fig. 5.

Fig. 4. Hydrogen absorption of samples/specimens made from alloy BT8 depending on heating conditions. Samples/specimens ϕ 15 and 20 mm.

Key: (1). Electric furnace. (2). Gas-fired furnace. (3). h.

Fig. 5. Depth of defective layer of alloy BT8 during heating in electric furnace depending on medium.

Key: (1). Defective layer. (2). Scale. (3). Alpha-deposited layer. (4). "transfer" layer. (5). Air argon. (6). h.



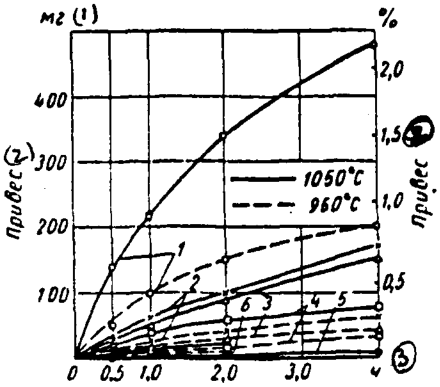


Fig. 6.

Fig. 7.

Fig. 6. Microhardness of samples/specimens made from alloy BT8 aft.. heating in different media.

Key: (1). kg/mm². (2). Microhardness. (3). h. (4). Air. (5). Argon. (6). (electric furnace). (7). Distance from surface of sample/specimen.

Fig. 7. Value of increase in weight depending on conditions of heating alloy BT8: °-° - gas-fired furnace; x-x - electric furnace; Δ-Δ with greasing glass + talc; ▫-▫- with coating with enamel "B"; ●-● - with coating with enamel "A"; ▲-▲ - in medium of argon.

Key: (1). mg. (2). Increase in weight. (3). h.

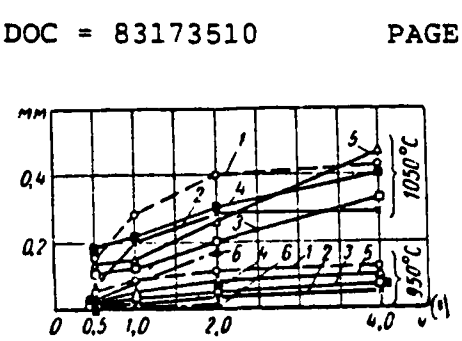


Fig. 8. The depth of the alpha-deposited layer in the samples/specimens from the alloys BT8 depending on medium, the temperature and the heating time: °--° - in the gas-fired furnace; x-x - in the electric furnace; □-□ - with coating enamel "A"; ■-■- with the coating with enamel "B"; Δ-Δ - with the facing by the water glass + talc; Δ-Δ - in the medium of argon.

Key: (1). h.

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With the renewal of work the blanks located in the furnace must be heated to the upper limit of deformation temperature.

During heating of blanks of titanium alloys it is necessary to provide minimum retention time of their at a temperature more than 800°C. Heating cylindrical blanks is better to produce induction with method. Annular billets should be heated in the electric systematic or two-chamber furnaces. Heating in the gas-fired furnaces can be

produced in the oxidizing atmosphere, moreover flame jet from the injectors must not wash the heated blanks.

Heating by induction ones with the method and in the electric furnaces is produced in the air atmosphere. Furnaces must be equipped with temperature controllers. The temperature in the working chamber of furnace must be uniform - the temperature differential in the different zones must not exceed in electric furnaces of 20°C, but in mazut of 30°C.

The advantage of induction method consists in the sharp shortening of the total time of heating (approximately/exemplaril 3-4 times in comparison with the heating in chamber type furnaces). With this method the depth of the alpha-deposited layer is decreased, the danger of the appearance of cracks is decreased during the deformation and the strength characteristics of the deformed semi-finished products are raised.

The advantage of induction heating show the following examples. The total heating time show the following examples. The total time of heating blanks with a diameter of 150 mm, of titanium alloy of the type BT3-1 in the three-layered inductor at the commercial frequency is $\approx$20 min. In this case the difference between the temperatures of surface and center descends to the minimum 1 min after the disconnection of current. With the common method of heating in the high-temperature box furnace this time would comprise about 75 min.

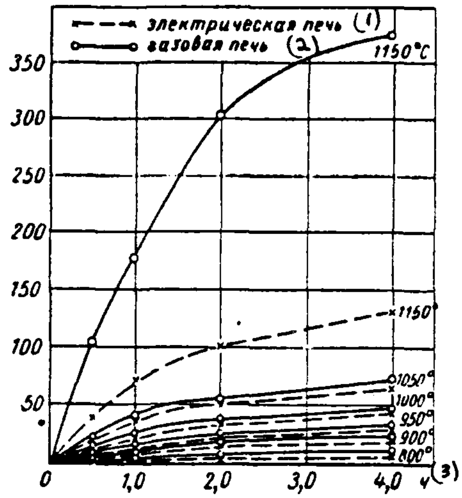

Fig. 9.

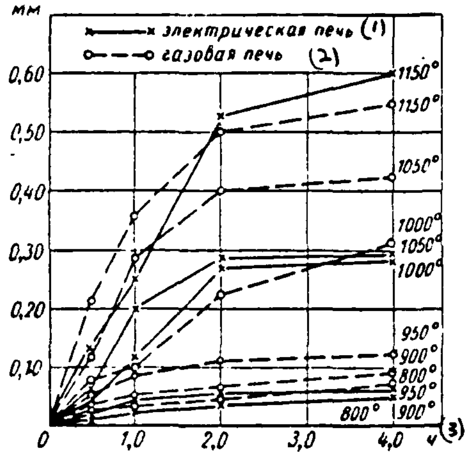

Fig. 10.

Fig. 9. Thickness of scale on samples/specimens made from alloy BT8 depending on temperature and period of heating.

Key: (1). electric furnace. (2). gas furnace. (3). h.

Fig. 10. Depth of alpha-deposited layer of alloy BT8 depending on temperature and heating time.

Key: (1). electric furnace. (2). gas-fired furnace. (3). h.

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Since grain-growth occurs above temperature of polymorphic transformation, it is expedient for the blanks of large cross sections to apply preheating before 800°C and then to accomplish/realize rapid heating in the inductor to the necessary temperature. This makes it possible to decrease the stay of the blank in the high-temperature range to 2-3 min.

The time of heating blanks with a diameter of 55 mm at the frequency of 2500 Hz is 4.5 min, whereas during the heating in the box furnace it is necessary to 27 min. The time of heating ingot with a diameter of 420 mm in the induction furnace with a diameter of 450 mm, which works at the commercial frequency, is 60 min. For the heating in the same inductor of the ingot with a diameter of 360 mm it is necessary to 70 min.

Modes/conditions of heating blanks by induction method.

Diameter of blank in mm ... 150 70-160.

Optimum frequency in per/s 50 500.

Diameter of blank in mm ... 50-120 30-80 15-40.

Optimum frequency in per/s ... 1000 2500 8000.

In the inductors it is expedient to produce heating in the large-series production of the relatively small nomenclature of blanks different in the diameter. With the large nomenclature of the blanks of different diameters and the limited volume of production the use/application of induction muffle furnaces, which work at the commercial frequency, is expedient. In the furnaces of such type is feasible heating blanks with a diameter of 20-150 mm. The construction/design of furnaces of such type makes it possible to produce heating metal in protective atmosphere. Induction muffle furnaces possess the best energy indices, easily yield to automation and rapidly are heated in comparison with the high-temperature resistance furnaces.

Preheating blanks during the heating in the two-chamber furnaces is produced to 800°C. The necessary for the preheating time after load into the chamber/camera with the temperature indicated is determined from the calculation 1 min to every 3 mm the maximum cross section of blank. Time, necessary for the heating after the transfer of blank of preheating chamber into the chamber/camera of final heating, the same as for the preheating.

The time, necessary for the heating in the one-way fired furnace

after the load of blanks into the chamber/camera with the temperature of the beginning of forging-stamping, is determined from the calculation 1 min to every 2 mm the maximum cross section of blank.

For the blanks with a diameter of SV 400 mm it is necessary to apply only two-stage heating. In the case of small outage the temperature of furnace, in which are located the blanks, should be lowered to 800°C and after interruption again raised it to the temperature of forging-stamping at a velocity, permitted by furnace output. With prolonged outages of blank of the furnace they unload and they pack to the dry floor/sex.

Technological processes are ductile.

The manufacture of forgings from the alloys of nonferrous metals is accomplished/realized according to the flow charts, given in Fig. 11 and 12 and in Table 16.

The diagrams of forging are divided into simple ones, when blank undergoes only upsetting or broach and complicated, that are the combination of two simple diagrams. In the latter case they are labelled depending on a quantity of the upsettings accepted and broaches:

diagram 1 - one upsetting and one broach to the size/dimension;

diagram 2 - two upsettings and two or one broach (see Fig. 11);

diagram 3 - three upsettings and three or two broaches (see Fig. 12).

In the diagram the forgings must be indicated the sequence of transitions and in each transition - value of upsetting blank; the arrangement of longitudinal axis according to the relation of the applied force; the method of upsetting and broach (upsetting into the end/face or with the insertion of faces to the "cap" of broach by sections with the indication of value or flattening throughout the entire length of blank).

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Shoeings I and the II groups of control, manufactured of the pressed rods with a diameter are more than 150 mm, for the purpose of guarantee in the forged semi-finished product of the highest and uniform mechanical properties it is necessary to hammer according to diagrams 2 or 3. The longitudinal axis of the initial pressed blank should be furnished in the forging in accordance with the form, the designation/purpose and the conditions for the work of part,

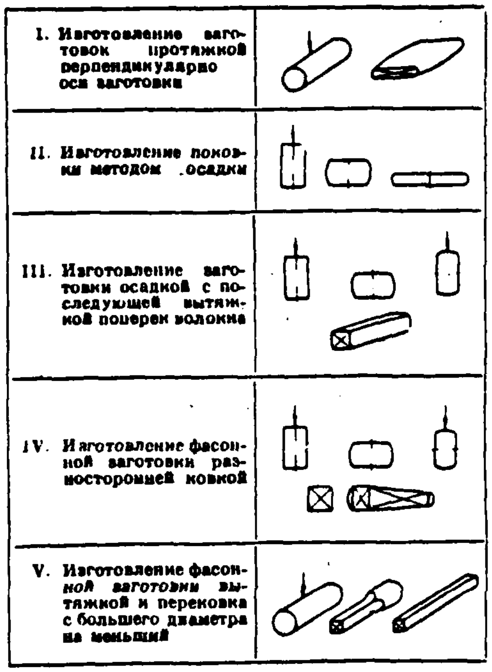
manufactured from this forging. For the forgings of axisymmetric form (of type" disk", ring, cylinder), articles of the type of flanges and the like the longitudinal axis of blank must be furnished in the direction of the axis of the symmetry of part, and in the forgings of another form - in the direction, in which it is necessary to ensure maximum mechanical properties.

For the purpose of the creation of the best conditions for the manifestation of the greatest plasticity of alloys and in particular magnesium ones, forging must be produced them in the figure faces.

Drop forging, which create the high deformation rates, it sh ld be in the beginning of process produced with taps with the degree of deformation for each impact/shock not more than 5-8%. The degree of deformation can be gradually increased in proportion to forging. During the forging on the presses the degree of deformation virtually is not limited.

Faces for the forging must be thoroughly ground; their edges must be rounded (R=10 mm not less). Before the ductile the faces must be warmed thoroughly to 300°C. In comparison with the upsetting on the unheated faces the degree of deformation with upsetting on the faces, heated to 300°C, it is raised on the average by 35% for the aluminum ones and by 25% - for titanium alloys.

16. Diagrams of forging blanks and forgings of alloys of nonferrous metals.



Key: (1). (I). The manufacture of blanks by broach is perpendicular to the axis/axle of blank. (II). Manufacture of forging by the method of upsetting. (III). Manufacture of blank by upsetting with the subsequent drawing across the grain. (IV). the manufacture of the annular billet of many-sided ductile. (V). Manufacture of annular billet by drawing and reshoeing from the larger diameter to smaller.

Notes: 1 - less plastic alloys MA3 and MA5 to deform according to diagrams I, III, IV and V is not recommended because of the initiation of the cracks (diagram I, III and V) of brittle

decomposition (diagram IV).

2. Operation of drawing relates to number of rigid diagrams of strain with large tensile stresses, in connection with which drawing of ductile under hammer does not have extensive application as a result of limited possibilities of increase in degree of deformation for one heating.

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With the upsetting on the cold faces there is no metal flow over the contact surface. The most intense metal flow, which is accompanie by refinement of grain and by the formation of the oriented structure in the direction of flow, occurs directly under the stagnant layer. The intensity of the metal flow in the middle of sample/specimen is less than in the layers, adjacent to the stagnation sections of contact surface. With the upsetting on the faces, heated up to 380°C, the stagnant layer is observed only in the range of the zone of initial contact, the metal flow over the contact surface occurs out of these boundaries/interfaces.

The decrease of the resistance to deformation with the upsetting on the heated faces occurs due to an increase in altitude of a layer of moving metal.

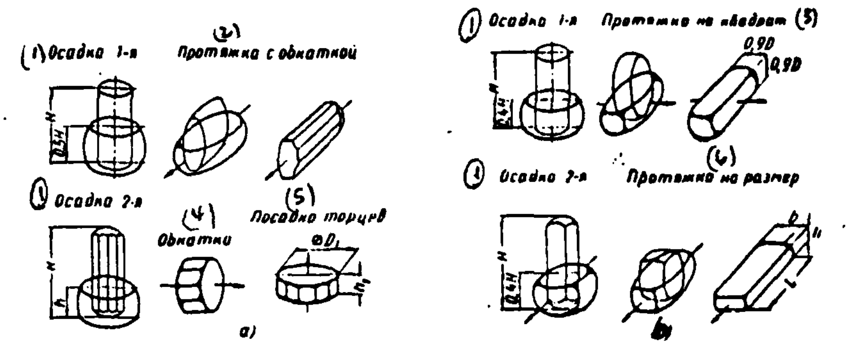

Fig. 11.

Key: (1). Upsetting. (2). Broach with rolling. (3). Broach to square. (4). Rolling. (5). Fitting/landing it is end. (6). Broach to size/dimension.

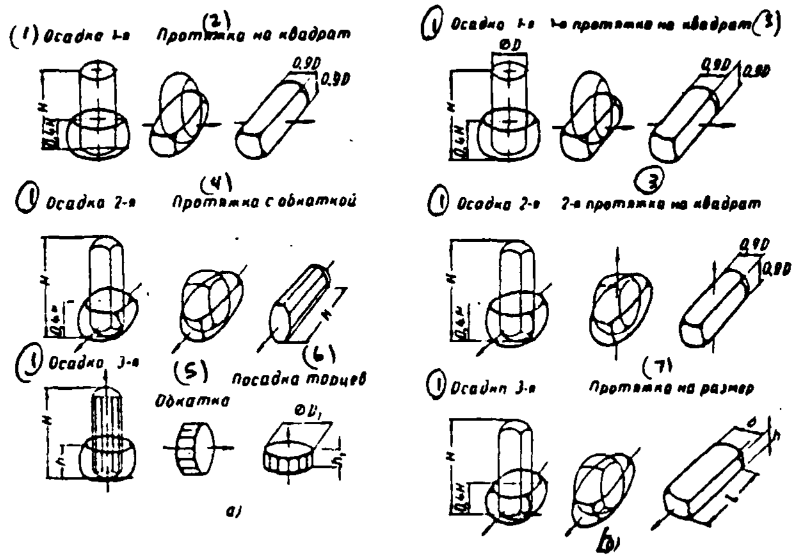

Fig. 12.

Key: (1). Upsetting. (2). Broach to square. (3). broach to square. (4). Broach with rolling. (5). Rolling. (6). Fitting/landing it is end. (7). Broach to size/dimension.

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In the case of upsetting on the cold faces of titanium blanks with ratio d/h=10 the real height/altitude of the layer, where the metal flow is observed, it composes 70-80% of the height/altitude of the upset blank, with upsetting on the heated faces - 90-100%. During forging of alloys, in particular aluminum ones and magnesium, for the purpose of the prevention of the adhesion of blanks to the faces the

latter should be periodically sprinkled the talc.

The standard technological processes of forging aluminum, magnesium and titanium alloys are given in Table 17-28.

Special features/peculiarities of forging copper alloys. The insignificant deformations to 30%, which can be used during forging of brass Л59 by free upsetting are virtually insufficient for working of brasses in the series production of free ductile. Therefore during the cold and hot working by the pressure of copper alloys they avoid this stress-strain state.

For increasing the plasticity of copper and copper alloys instead of the forging by free upsetting are applied the upsetting with the lateral pressure or the extrusion/pressing ingots by extrusion in the container.

In order to raise the plasticity of brass Л59 and other copper alloys with upsetting, the values of second and third main compressive stresses increase. Upsetting with the higher lateral pressure in comparison with the free upsetting reach by this way.

If during the free upsetting, which is accompanied by virtually free broadening, brass Л59 converts/transfers into the brittle state,

then with the upsetting with the high lateral pressure, for example, in the collars, the plasticity of brass considerably is raised (Fig. 13).

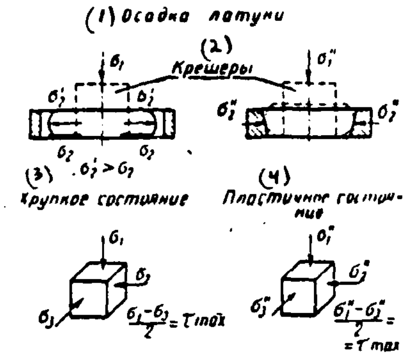
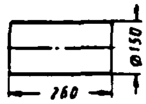
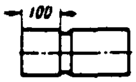
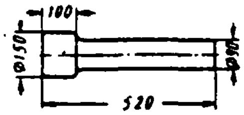


Fig. 13. Upsetting brass Л59 with the lateral pressure in the collar.

Key (1). Upsetting brass. (2). Crushers. (3). Brittle state. (4). Plastic state.

17. Standard technological process of forging aluminum alloy.

(1) Эскизы переходов	(2) Операция. Степень деформации	(3) Оборудование. Форма бойков
	(4) Резка заготовок (6) Нагрев до 480° С	(5) Дисковая пила (7) Камерная электрическая печь
	(8) Наметка	(9) Ковочный молот 1 Т (10) Бойки гладкие
	(11) Оттяжка конца	(9) Ковочный молот (12) Бойки фигурные

Key: (1). Drawings/drafts of transitions. (2). Operation. Degree of deformation. (3). Equipment. Form of faces. (4). Cutting blanks. (5). Circular saw. (6). Heating to 480°C. (7). Box electrical furnace. (8). Rough draft. (9). Swage 1 T. (10). Faces, smooth. (11). Drawing out of end. (12). Faces, figure.

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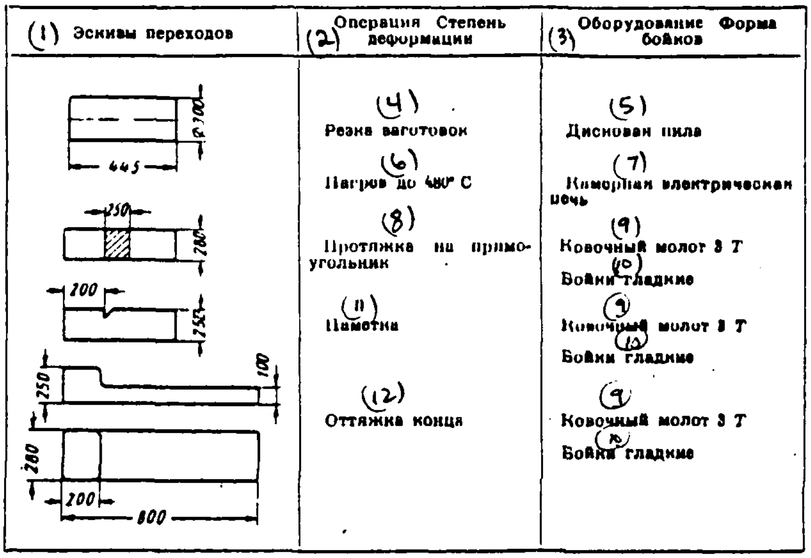
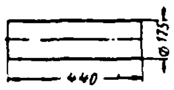
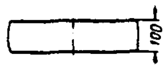
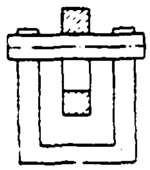
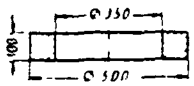
18. Standard technological process of forging aluminum alloy.



Key: (1). Drawings/drafts of transitions. (2). Operation. Degree of deformation. (3). Equipment. Form of faces. (4). Cutting blanks. (5). Circular saw. (6). Heating to 480°C. (7). Box electrical furnace. (8). Broach to rectangle. (9). Swage 3 T. (10). faces, smooth. (11). Rough draft. (12). Drawing out of end.

19. Standard technological process of forging aluminum alloy.

(1) Эскизы переходов	(2) Операция. Степень деформации	(3) Оборудование. Форма бойков
	(4) Резка заготовок (6) Зачистка торцов	(5) Дисковая пила
	(7) Нагрев до 470° С	(8) Камерная электрическая печь
	(9) Осадка	(10) Ковочный молот 3 Т (11) Бойки гладкие
	(12) Прошивка	(10) Ковочный молот 3 Т (11) Бойки гладкие
	(9) Нагрев до 470° С	(13) Камерная электрическая печь
	(14) Раскатка на оправке	(10) Ковочный молот 3 Т
	(15) Правка по торцам	

Key: (1). Drawings/drafts of transitions. (2). Operation. Degree of deformation. (3). Equipment. Form of faces. (4). Cutting blanks. (5). Circular saw. (6). Trimming of ends/faces. (7). Heating to 470°C. (8). Box electrical furnace. (9). Upsetting. (10). Swage 3 t. (11). Faces, smooth. (12). Piercing. (13). Box electrical furnace. (14). Unrolling on mount/mandrel. (15). Straightening/trimming along ends/faces.

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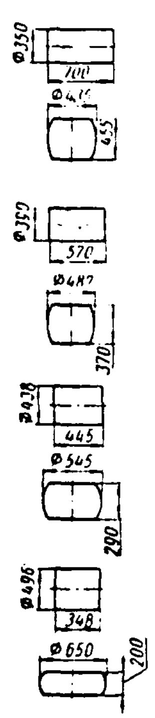
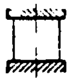
20. Technology of manufacture of forgings for disks from alloys BM17 and MA3.



(1) Эскиз перехода	(2) Операция. Степень деформации	(3) Оборудование. Форма бойков	(4) Температура в °C	(5) Режим повторных нагревов
	(6) Литая или прессованная заготовка, вес 112 кг	–	–	(7) Гомогенизирующий отжиг при 490—500° C в течение 10—15 ч; MA3 при 415° C 40 ч
	(8) Осадка, 35%	(10) Пресс 300 т и выше 	BM17 600—300; MA-3 390—250	–
	(9) Вытяжка, 25%			–
	(8) Осадка, 35%		BM17 450—300; MA3 390—250	(11) Нагрев. BM17 — 450° C, MA3 — 390° C
	(9) Вытяжка, 20%			–
	(8) Осадка, 35%			(11) Нагрев: BM17 — 450° C; MA3 — 390° C
	(9) Вытяжка, 20%			–
	(8) Осадка, 43%		BM17 400—300; MA3 350—230	(11) Нагрев: BM17—400° C; MA3 — 350° C

Key: (1). Drawing/draft of transition. (2). Operation. Degree of deformation. (3). Equipment. Form of faces. (4). Temperature in °C. (5). Mode/conditions of reheatings. (6). Cast or pressed blank, weight of 112 kg. (7). Homogenizing annealing with 490-500°C for 10-15 h; MA3 at 415°C 40 h. (8). Upsetting. (9). Drawing. (10). Press is 300 t and above. (11). Heating.

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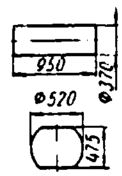
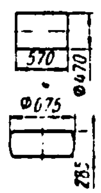
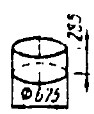
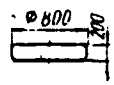
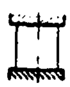
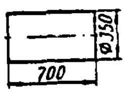
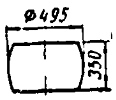
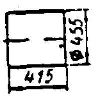
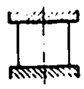
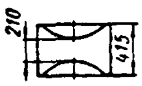
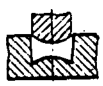
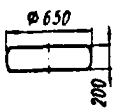
21. Technology of manufacture of forgings for disks from alloys BM17 and MA3.

(1) Эскиз перехода	(2) Операция. Степень деформации	(3) Оборудование. Форма бойков	(4) Температура ковки в °C	(5) Режим повторных нагревов
	Литая заготовка (6)	—	—	(7) Гомогенизирующий отжиг: 490—500° C в течение 10—15 ч; для MA3 при 415 ± 5° C в течение 40 ч
	(8) Осадка, 50%	(9) Пресс 3000 т и выше	BM17 500—300; MA3 380—250	(10) Нагрев: BM17 — 500° C; MA3 — 390° C
	(11) Вытяжка, 20%	(9) Пресс 3000 т и выше	BM17 500—300; MA3 390—250	—
	(8) Осадка, 50%		BM17 400—300; MA3 — 390—250	—
	(12) Штамповка в закрытом штампе. Заготовка выгибается 2 раза		BM17 450—300, MA3 300—250	(10) Нагрев: BM17—450° C; MA3—300° C
	(13) Осадка и правка поковки по размерам		BM17 400—300; MA3 350—250	(10) Нагрев: BM17—400° C; MA3—350° C

Key: (1). Drawing/draft of transition. (2). Operation. Degree of deformation. (3). Equipment. Form of faces. (4). Temperature of forging in °C. (5). Mode/conditions of reheatings. (6). Casting. (7). Homogenizing annealing: 490-500°C for 10-15 h; for MA3 at 415±5°C for 40 h. (8). Upsetting. (9). Press is is 3000 t and above. (10).

Heating. (11). Drawing. (12). Flashless die forging. Blanks are bended out 2 times. (13). Upsetting and straightening/trimming forging according to sizes/dimensions.

22. Technology of manufacture of forgings for disks from alloys BM17 and MA3.

(1) Эскиз перехода	(2) Операции. Степень деформации	(3) Оборудование. Форма бойков	(4) Температура в °С	(5) Режим повторных нагревов
	(6) Литая заготовка	—	—	(7) Гомогенизирующий отжиг: 490—500° С в течение 10—15 ч; для МА3 при 415° С ± 5° С в течение 40 ч
	(8) Осадка, 50%	(9) Пресс 3000 т и выше	ВМ17 500—300; МА3 — 300—250	(10) Нагрев: (11) сплава ВМ17—500° С; сплава МА3—300° С
	(12) Вытяжка, 18%			—
	(13) Штамповка, 50% (в центре диска)	Пресс 3000 т и выше 	ВМ17 450—300; МА3 380	Нагрев: ВМ17 450° С; МА3 380° С
	(14) Свободная осадка, 50%		ВМ17 400—300 МА3 350—250	(10) Нагрев: ВМ17—400° С; МА3 350° С

Key: (1). Drawing/draft of transition. (2). Operations. Degree of deformation. (3). Equipment. Form of faces. (4). Temperature in °C. (5). Mode/conditions of reheatings. (6). Casting. (7). Homogenizing annealing: 490-500°C for 10-15 h; for MA3 at 415°C±5°C for 40 h. (8).

Upsetting. (9). Press 3000 t and above. (10). Heating. (11). alloy. (12). Drawing. (13). Stamping, 50% (in center of disk). (14). Free upsetting, 50%.

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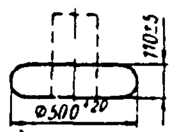
23. Technology of manufacture of forgings from alloy "MA5.

(1) Эскиз перехода	(2) Операция	(3) Температурный режим: (4) время нагрева в ч	(5) начало операции, (8) в °C	(6) конец операции, (8) в °C	(7) Оборудование. Инструменты
	(11) Мерный слиток после обточки 505×1750 мм	—	—	—	(12) Токарный станок
(9) Осадка	(13) Гомогенизация:				
	I ступень (14)	6	390±10		(15) Колодцы
	II ступень (14)	8	390±10		
	Нагрев (16)	5	300—330		(17) Печь
	(18) Прессование прутка на Ф 260 мм	—	330—300		(19) Горизонтальный пресс 12000 т, контейнер Ф 520 мм. Матрица Ф 262 мм
(10) Прошивка	(20) Резка в меру l = 480 мм	—	—	—	(21) Дисковая пила
	(22) Обточка заготовки с Ф 200 мм на Ф 250 мм	—	—	—	(23) Токарный станок
	(24) Зачистка заусенцев и центров	—	—	—	(25) Бормашина
	Нагрев (16)	2.5	350—380		Печь (17)
	(26) Осадка и прошивка заготовок	—	380	300	(27) Пресс 6000 т. (28) Клещи
	Старение (29)	24	185		(17) Печь
	Травление и зачистка (30)				(31) Травильная ванна и бормашина
	Оксидирование (32)	—		—	(33) Ванна оксидировальная
	Приемка ОТК (34). Сдача на склад (35).				

Key: (1). Drawing/draft of transition. (2). Operation. (3). Temperature conditions. (4). heating time in h. (5). beginning of operation. (6). end of operation. (7). Equipment. Instruments. (8). in °C. (9). Upsetting. (10). Piercing. (11). Measured ingot after machining 505×1750 mm. (12). Lathe. (13). Homogenization. (14). step/stage. (15). Wells. (16). Heating. (17). Furnace. (18). Extrusion/pressing rod on ∅ 260 mm. (19). Horizontal press 12000 t, container ∅ 520 mm. Die ∅ 262 mm. (20). Cutting into measure

l=480 mm. (21). Circular saw. (22). Machining of blank with ∅260 mm on ∅250 mm. (23). Lathe. (24). Deburring and centers. (25). Drill. (26). Upsetting and piercing of blanks. (27). Press 6000 T. (28). Tongs. (29). Aging. (30). Etching and trimming. (31). Etching bath and drill. (32). Oxidizing. (33). Bath, oxidized. (34). Inspection/acceptance OTK. (35). Delivery to storage.

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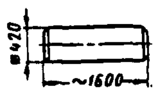
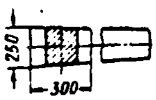
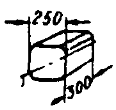
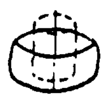
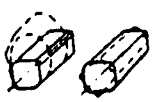
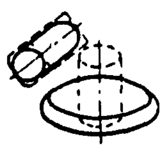
24. Technological process of forging washers[1] on titanium alloys.

FOOTNOTE [1]. This technological process provides obtaining in the forging of more uniform and finer/smaller structure and higher mechanical properties. ENDFOOTNOTE.

(1) Эскиз перехода	(2) Операция	(3) Оборудование и указания по режиму ковки
	(4) Нагрев слитка или блюмса	(5) Печь
	(6) Протяжка слитка на квадрат 250 мм. Рубка на мерные заготовки	(7) Пресс 2000 *T* или молот 5 *T*
	(8) Нагрев заготовки	(5) Печь
	(9) Подкатка на круг *200 мм. Осадка*	(10) Пресс 3000 *T* или молот 5 *T*. Осадка-протяжка производится: а) с температуры β-области, б) с температуры β-области близкой к границе полного $\alpha + \beta \rightleftarrows \beta$- превращения и *в) при температуре* $\alpha + \beta$*-области*
	(11) Протяжка на квадрат 200 мм со сменой граней и ребер	
	(12) Нагрев. Подкатка и осадка на *h=100 мм*	(5) Печь. (13) *Осадку* производить при температуре, соответствующей $\alpha + \beta$-области со степенью деформации не более 40% за вынос

Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment and indication under conditions of forging. (4). Heating ingot or bloom. (5). Furnace. (6). Broach of ingot to square 250 mm. Cutting

to the measured blanks. (7). Press 2000 T or hammer 5 t. (8). Heating blank. (9). Fullering on the average 200 mm. Upsetting. (10). Press 2000 T or hammer 5 T. Upsetting-broach is produced: a) from the temperature of β-region, b) from the temperature of β-region close to the boundary/interface of complete $\alpha+\beta \rightleftarrows \beta$-transformation and c) at a temperature of $\alpha+\beta$-region. (11). Broach to square 200 mm with replacement of faces and edges/fins. (12). Heating. Fullering and upsetting on h=100 mm. (13). Upsetting produce at temperature, which corresponds to $\alpha+\beta$-region with degree of deformation is not more than 40% for carrying out.

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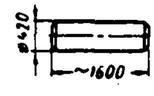
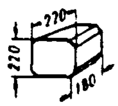
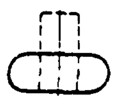
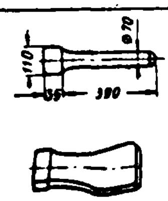
25. Technological process of smith forging of annular billets prior to stamping of large-size blades of titanium alloys.

(1) Эскиз перехода	(2) Операция	(3) Оборудование и указания по режиму ковки
	(4) Нагрев слитка	(5) Печь
	(6) Протяжка слитка на квадрат 200 мм. Рубка на мерные заготовки Нагрев заготовок	(7) Пресс 2000 Т или молот 3 Т
	(8) Подкатка на круг 200 мм. Осадка	(9) Пресс 2000 Т или молот 3 Т. Осадка-протяжка производится 2 раза с температуры β-области с постепенным снижением до температуры полного превращения
	(10) Протяжка на квадрат 180 мм со сменой граней и ребер	
—	Нагрев (11)	Печь (5)
	(12) Обкатка и осадка	(13) Молот 3 Т. Осадка-протяжка производится 2 раза с температуры α + β-области
	(14) Протяжка на квадрат 110 мм	
—	Нагрев (11)	Печь (5)
	(15) Оттяжка хвостовой части заготовки	(16) Молот 3 Т

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Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment and indication under conditions of forging. (4). Heating ingot. (5). Furnace. (6). Broach of ingot to square 200 mm. Cutting to the measured blanks. Heating blanks. (7). Press 2000 T or hammer 3 t. (8). Fullering on the average 200 mm. Upsetting. (9). Press 2000 t or hammer 3 t. Upsetting-broach is produced 2 times from the temperature of β-region with the gradual reduction/descent to the temperature of quantitative transformation. (10). Broach to square 180 mm with replacement of faces and edges/fins. (11). Heating. (12). Rollin and upsetting. (13). Hammer 3 t. Upsetting-broach is produced 2 times from the temperature of $\alpha+\beta$-region. (14). Broach to square 110 mm. (15). Drawing out of tail section of blank. (16). Hammer 3 t.

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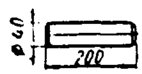
26. Technological process of forging blanks prior to stamping of lever of titanium alloys.

(1) Эскиз перехода	(2) Операция	(3) Оборудование
	(4) Резка заготовок расчетной длины и нагрев до заданной температуры.	(5) Печь
	(6) Вытяжка на плоских бойках	(7) Молот 200—450 кГ
	(8) Разрубка. Нагрев	
	(9) Гибка на заданный угол. Нагрев	(7) Молот 250 кГ
	(10) Вытяжка концов рычага	
	(11) Отрубить излишки, выправить поковку	

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Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment. (4). Cutting blanks of calculated length and heating to prescribed/assigned temperature. (5). Furnace. (6). Drawing on platens. (7). Hammer 250-450 kgf. (8). Chopping. Heating. (9). Bending to preset angle. Heating. (10). Drawing of ends of lever. (11). To chop off excesses, straighten-trim forging.

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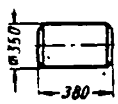
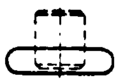
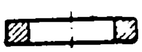
27. Technological process of forging and unrolling rings from titanium alloys.

(1) Эскиз перехода	(2) Операция	(3) Оборудование
	(4) Нагрев заготовок	(5) Печь
	(6) Осадка заготовки	(7) Молот 5—15 Т
	(8) Прошивка осаженной заготовки	
	(9) Расковка на оправке 140—180 мм	(10) Молот роговой 4,5 Т
	(11) Калибровка по высоте. Нагрев	(7) Молот 7 Т
	(9) Расковка на оправке ⌀ 230—250 мм	(10) Молот роговой 4,5 Т
	(12) Калибровка по высоте	(7) Молот 7 Т
	(13) Нагрев. Раскатка на специальном стане	(5) Печь

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Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment. (4). Heating blanks. (5). Furnace. (6). Upsetting blank. (7). Hammer. (8). Piercing of upset blank. (9). Upsetting on mount/mandrel 150-180 mm. (10). Hammer horn 4.5 T. (11). Calibration on height/altitude. Heating. (12). Calibration on height/altitude. (13). Heating. Unrolling on the special mill.

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28. Technological process of bending and twisting of parts from titanium alloys.

(1) Сплав	(2) Температура нагрева под гибку и закручивание в °C не выше	(3) Температура конца гибки и закручивания °C не ниже	
		(4) под молотом	(5) под прессом
BT-1	850	750	650
BT4-0			
OT4-1	880		700
OT4	900		
OT4-2	950	900	850
BT4	920	850	800
BT3-1	930		
BT5	1000	920	850
BT5-1			
BT6C	900	800	750
BT6	920	850	800
BT8	950		
BT9			
BT14	900	800	750
BT15	800	650	600
BT16	830	700	650
BT20	980	900	850
BT22	850	750	700

Notes: 1. In order to avoid considerable grain-growth and not to worsen/impair mechanical properties, the heating temperature must be lower than temperature of the complete $\alpha+\beta\rightarrow\beta$-transformation of the alloy (see Chapter 2 Tables 10).

2. Surface of bend or twisted surface must not have external

defects in the form of shortenings, dents, folds, motches and cuts from machining. The surface finish is achieved by thorough forging or machining. At the worst the defects/flaws can be distant by slanting trimming by emery wheel. Otherwise the surface flaws will serve as stress concentrators and contribute to formation of wrinkles and cracks at the moment of bend or twisting.

3. Surface of blank must not have deeply penetrating alpha-deposited layer, which is formed in process of prolonged heating under forging at temperatures, which exceed temperature of complete polymorphic transformation. The alpha-deposited layer has low technological plasticity and therefore can be formed deep cra s on the surface in the place of bend and twisting.

4. Blank must be evenly thoroughly heated throughout entire section/cut of bend or twisting.

5. Faces must be heated to temperature not lower than 250°C.

Key: (1). Alloy. (2). Heating temperature under bending and twisting in °C is not above. (3). Temperature of end of bending and twisting of °C is not below. (4). under hammer. (5). under press.

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A change in the relationships/ratios between the stresses with the upsetting in the ring can be represented in the form

$$\sigma_1'' > \sigma_1; \quad \sigma_2'' \approx \sigma_3'' > \sigma_2 \approx \sigma_3.$$

Lateral pressure on the surface of ingot raised all compressive principal stresses and lowered the stretching deformations and stresses/voltages. The plasticity of alloy considerably increases as a result.

In the process of this upsetting in the collars, the brittle state of alloy is not observed even during the deformation, which exceeds 35%.

The upsetting of copper and copper alloys in the collars with the high lateral pressure is produced with the observance of the general rule: free upsetting of blank to the emergence of the contact of the upset metal with the internal wall of instrument (ring) can be produced with the degree of deformation, with which copper or alloy

on its basis do not convert/transfer into the brittle state. As it was shown above, this degree of deformation for brass Л59 was equal to 30%.

Lateral pressure with the sediment/residue can be introduced, also, from the very beginning of upsetting blank. For this is applied the upsetting with the lateral pressure in the ring, in which is arranged/located the blank with possible the minimum clearance (Fig. 14). With the residue according to this method the ring undergoes elongation. The force necessary for the elong'tion of ring with the residue, and creates lateral pressure. The value of lateral pressure is determined by the strength of the material of ring. The greate the strength of ring, the greater the lateral pressure. With the upsetting in the ring the given rule of upsetting with the lateral pressure they do not apply, since ultimate strain, which shifts the upset metal into the brittle state with the method of upsetting in question, considerably increases.

Upsetting with the complete lateral pressure in the ring, with the lateral pressure from the very beginning of deformation is applied for forging of the low-plasticity and hard-to-deform copper alloys.

After upsetting the blanks undergo finishing operation - rol'ing

on the smooth ones or in the notched strikers (Fig. 15).

Drawing is applied for obtaining the forgings of intended sizes or for obtaining of rods or bands of off-measure length, from which are cut or are cut in the hot state measured blanks prior to further forging or stamping. The upsetting-drawing is applied for the thorough study of metal.

For the drawing are applied flat/plane or notched strikers (Fig. 16), and also swages.

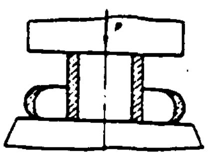

Fig. 14.

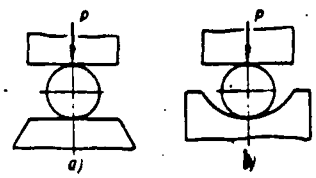

Fig. 15.

Fig. 14. Upsetting with complete lateral pressure.

Fig. 15. Finishing (rolling) blanks afterward residues.

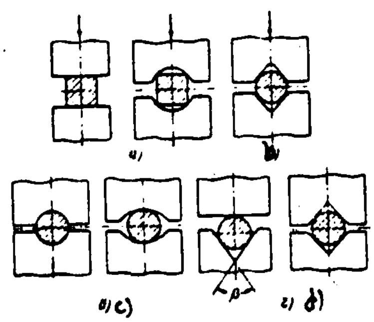

Fig. 16. Faces, used for drawing: a) flat/plane; b) carved; c) semicircular carved; d) rhombic carved.

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Notched strikers are semicircular and rhombic with angle of

β=90-120°. The productivity of drawing on the notched strikers by 20-40% is higher than on the flat/plane ones.

Exhaust forging operations are accomplished/realized on the swages or the presses, and also on the forging rolls. Drawing out of the ends of the pressed or rounds from copper and copper alloys, for example, for the capture/grip with further draw plate operations is produced mainly on the forging rolls.

Exhaust operations in the limits of the small weighing of blanks are produced with the hand feed, and the blanks of large weighing - with the aid of the outdoor/floor or suspension manipulators.

The platens for the exhaust operations (Fig. 17) apply for the highly ductile alloys, and notched strikers (especially semicircular) - for the less plastic ones, since they because of the comprehensive reduction prevent the emergence of side tensile (destructive) stresses.

In the process of the drawing of copper alloys it is necessary to attain the great lengthening of blank and its smaller broadening. This is reached due to the small supply of blank for each reduction. The less the broadening and the greater the elongation of blank with each reduction, the greater is obtained the reduction, i.e., the more

intensely the process of drawing occurs.

The value of reduction (degree of deformation on the height) should be designated, taking into account the technological plasticity of one or the other copper alloy, and also the need for the sufficiently good study of metal. With the high degrees of reduction for each press (impact/shock) is possible the formation of the clamps (folds) of the metal, to which contribute the sharp or worn edges of faces.

Drawing with the consecutive one-sided reduction throughout entire length before the turning is more favorable.

Drawing consists of the elements of the separate upsettings, consecutively/serially made in the process of the technological operations of drawing. But it differs from the upsetting by the more uniform conditions for the comprehensive metal deformation, which is evident from the diagram, represented in Fig. 18.

With the upsetting-drawing the separate zones of deformation, which are formed during the upsetting, change their position due to the turning. In particular the 1st zone of the smallest deformation, obtained with the residue, in the process of exhaust operations is converted into the 2nd zone of larger deformation.

During the drawing after each press (impact/shock) the upsetting occurs. The conducted investigations showed that the degree of deformation for the course of machine with the upsetting of brass Л59 cannot be higher than 30%, since large deformations give alloy with the upsetting into the brittle state with crack formation. Therefore during the drawing of brass Л59 and other copper alloys the degree of deformation must not exceed 30%.

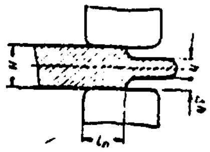

Fig. 17.

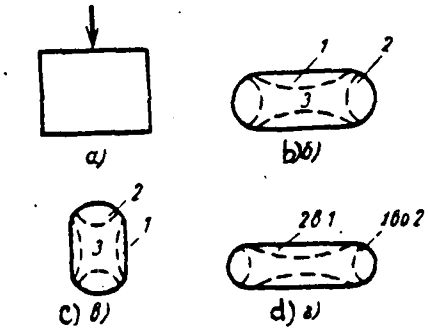

Fig. 18.

Fig. 17. Diagram of drawing on platens.

Fig. 18. Metal deformation during drawing: a) blank; b) deformation after first impact/shock during drawing; c) groove of blank on 90 d) deformation after turning and second impact/shock during drawing.

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Hence it follows that the copper alloys during the smith forging by drawing on the platens do not allow/assume working with the high deformations.

Therefore in the plant practice in the series production the ingots of copper alloys rarely are worked by free ductile. The method of forging with is changed only during the manufacture of unit

articles or during the manufacture of short runs. Moreover, in the case of applying the exhaust operations with the method of forging it is necessary forging to produce in the notched strikers, which are selected depending on the plasticity of alloy according to Table 11 (Chapter 2). In the series production the ingots from the copper alloys are deformed by extrusion/pressing on the horizontal presses.

During the extrusion/pressing by extrusion the mechanical diagram of deformation is characterized by the nonuniform cubic compression, during which main compressive stresses considerably are higher in comparison with the ductile upsetting and the drawing. Therefore during the extrusion/pressing by ingot stripping from the copper alloys undergo considerable deformations, in this case the pressed metal does not convert/transfer into the brittle state.

Industrial Processes of Stamping.

Stamping the alloys of nonferrous metals to more preferably produce on the hydraulic, mechanical and friction presses, since at the smaller than on the hammers, deformation rate more uniformly flows metal and, therefore, less is formed defects/flaws on the surface of stampings. The diagrams of deformation should be selected such, from which obtaining the required form occurs due to the extrusion (extrusion), but not due to upsetting.

Drop forging.

In the absence of the press equipment for stamping they manufacture on steam-air and other swaging hammers with a weight of the falling/incident parts of 500-2000 kgf even more, in the open dies and predominantly from those pressed (aluminum, magnesium, copper) - rolled and forged (titanium) blanks.

However, with stamping under the steam-air hammers it is recommended to treat only more plastic alloys for the production of the parts of low weight.

From the alloys of average/mean plasticity on the swaging hammers it is possible to make the parts of simple form and only when initial blank is close in form and configuration of the obtained stamping. It is expedient to deform the parts of different complexity of the less plastic alloys for two transitions of press.

In the case of the fulfillment of works in the open single-pass dies on hammers stamping must be begun with taps, gradually strengthening them. From the moment/torque of forming the flash, in connection with the more favorable diagram of the stressed state, the

degree of deformation is not limited. To apply multipass dies/stamps is inexpedient in connection with the fact that after each deforming operation it is necessary to remove defects/flaws on the surface of blanks.

The redistribution of initial material is usually produced by free ductile.

Press forging.

There are two methods of the stamping: 1) from the preliminarily prepared annular billet, which is open ductile on the flat/plane or shaped faces and in its configuration is close to the finished stamping. Then annular billet is stamped in the single-pass forging die with one or several heatings; 2) measured blank without the preliminary forging directly enters the stamping. The filling of the die cavity with metal depends on the form of blank and groove in the die/stamp.

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With the press forging should be designated two transitions - preliminary and final, since with the degree of deformation of more than 40% for one stroke of press in the flash the considerable volume

of metal is extruded, in consequence of which the die cavity is filled not completely.

In the case of the combined (press hammer) stamping for two transitions, first transitions it is necessary to fill on the press, the second - on the hammer.

During the manufacture of complicated blanks with the sharp transitions between the sections/cuts additional transitions for the preliminary deformation on the press must be provided for.

Repeated stamping is produced with intermediate trimming of flash, with the subsequent etching and the trimming of surface flaws.

Repeated stamping can be accomplished/realized in one die/stamp or in the special preliminary dies/stamps, which gradually lead blank to the final dimensions. Preliminary transitions are designed just as for the stampings made of structural steel. The following procedure of the determination of form and sizes/dimensions of the section/cut of preliminary transition (Fig. 19) is recommended for blanks with the double-T sections/cuts. The shaded cross-sectional areas (Fig. 19a and b) must be equivalent. In the preliminary transition (Fig. 19a) the fabric is made more thickly and a radius of coupling edge/fin with the fabric is more, due to what the edge/fin become

below. On the final transition excessive metal must be directed from the fabric of preliminary section/cut into the edge/fin, without having given to it to leave in the flash. Certain excess of metal, which appears as the continuation of the fabric of section/cut, is provided for this in the section/cut of preliminary transition after the edges/fins. The excess of metal has a thickness h radius R of coupling with the edges/fins the same as fabric. The length l of the excess of metal depends on thickness h and radius R of coupling with the edges/fins the same as fabric. The length l of the excess of metal depends on thickness h and radius R and usually do not exceed 10-15 mm. In this case double-T section/cut can be considered as two cross-shaped sections/cuts, put one to another by fabrics. With final rolling of this section/cut the excessive metal, arranged/located after the edges/fins, immediately forms flash and partially goes into the edge/fin (see Fig. 19b), and the metal located between the edges/fins, it goes only to the filling of edges/fins. This form of the section/cut of preliminary transition provides obtaining the blanks of double-T section/cut without the defects/flaws. The forms of the sections/cuts of preliminary and final transitions for the standard stamping are shown in Fig. 20.

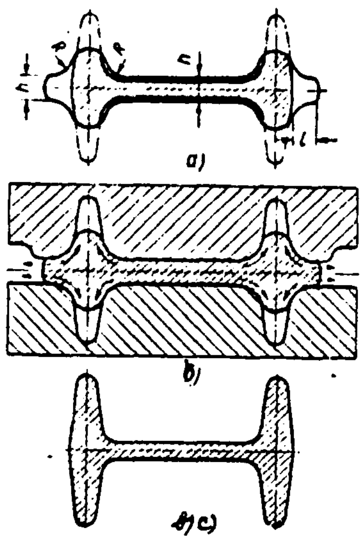

Fig. 19.

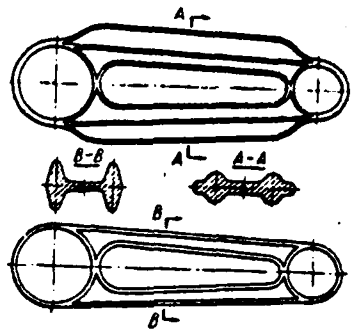

Fig. 20.

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Trimming flash. In stampings from the alloys of nonferrous metals flash they trim as a rule in the trimming dies. To the cutting of flash in stampings from the aluminum and magnesium alloys on the saw bands they apply only in the cases of large overall dimensions and the small numbers of stampings, when the manufacture of the trimming dies is inexpedient. To the cutting of flash in the dies/stamps in stampings from the aluminum and copper alloys they produce in the cold state, of the magnesium alloys MA2 and BM65-1 at a temperature not lower than 220°C of the alloys MA3 and MA5 in the range of temperatures of 220-300°C, of titanium alloys - at

600-800°C.

Depending on the form of stampings trimming flash is produced either with the pushing or cutting male die/punch. With the cutting by the pushing male die/punch (Fig. 21) clearance δ between the matrix/die and the male die/punch they designate according to Table 29 depending on height/altitude h, equal to distance from the cutting edge of matrix/die to the plane of the adjoining of the male die/punch (see Fig. 21). At the variable/alternating height/altitude for this stamping they designate clearance δ on the smallest height.

In the case of trimming by the cutting male die/punch (see Fig. 21) clearance δ is determined according to tables 30 depending on thickness a of the shorn flash.

The binding face of male die/punch to the stamping must be thoroughly urged to avoid the formation of the pressures/clamps, which can lead to the waste/reject, in particular, if pressures/clamps occur on the non-machined surfaces.

The piercing of holes in the stampings is produced under the conditions of the cutting male die/punch (Fig. 22a), when the broached place rests on the matrix/die in contrast to the steel stampings, where the piercing is produced by the predominantly

pushing male die/punch (Fig. 22b).

Effort/force for trimming of flash is determined from the formula

$$P = \sigma_{cp} \Pi (a + \delta + 1,2R),$$

where σ_{cp} - tensile strength immediately in kg/mm²; Π - perimeter of shear/section in mm; a - nominal thickness of flash in mm; δ - positive deviation of the thickness of forging in mm; R - radius at the output/yield to the barb bridge in mm.

The force for the piercing is determined from the formula

$$P_{np} = \sigma_{cp} \Pi (a_1 + \delta_1),$$

where a_1 - actual thickness of the punctured cross connection in mm; δ_1 - positive deviation of the thickness of cross connection.

Flashless die forging (Figs. 23-24).

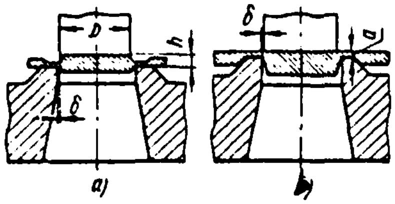

Fig. 21.

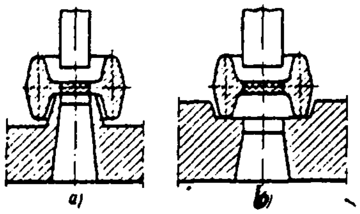

Fig. 22.

29. Clearance δ between matrix/die and male die/punch with cutting.

h	D	a	δ
а) Обрезка облоя толкающим пуансоном			
(1) До 10	(1) До 30	—	0,5
10—25	30—60	—	1,0
(2) Св. 25	(2) Св. 60	—	1,5
б) Обрезка облоя режущим пуансоном			
—	—	1—1,2	0,10
—	—	1,5	0,15
—	—	2,0	0,17
—	—	3,0	0,25
—	—	4,0	0,3
—	—	5,0	0,4
—	—	6,0	0,5

Key: a). Trimming flash by the pushing male die/punch. b). Trimming flash by cutting male die/punch. (1). To. (2). Above.

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The major advantage of flashless die forging (flashless) is considerable metal savings because of the absence of projecting edge, technological of necessary in the open dies. With the higher cost/value of alloys in nonferrous metals in comparison with steel,

this advantage has vital importance. Also need and additional operations and instrument for flash trimming drops out.

For alloys which have the lowered/reduced plasticity, with flashless die forging the more favorable diagram of the stress-strain state with the sharply pronounced cubic compression with relatively low tensile stresses occurs.

Flashless die forging can be produced both on the hammers and on the presses. On the hammers it is possible to stamp only alloys with the increased plasticity, i.e., the same as with open-die forging.

For flashless die forging the most adequate machines are the crankshaft, friction and hydraulic presses.

Stamping in the horizontal forging machines.

Horizontal-forging machines (GKM) relate to the type of crankshft-brass mechanisms, whose slider, which carries working tool, has reciprocating motion in the horizontal direction. Most widely used and characteristic for GKM in connection with titanium alloys and other structural materials operation - upsetting.

Examples of technological stamping passes in the horizontal

forging machine for the aluminum and magnesium alloys. 1. Stamping part of type rod with boss in machine 400 T (Fig. 25). They stamp the blank with a diameter of 35 and with a length of 315 mm of the alloy AK4-1 in three transitions: in the first groove in the male die is accomplished/realized the conical set of metal; in the second groove - set of the second cone; in the third groove - thickening (head) finally takes shape in the die to the necessary sizes/dimensions with the insignificant end flash, which is removed during the machining of stamping.

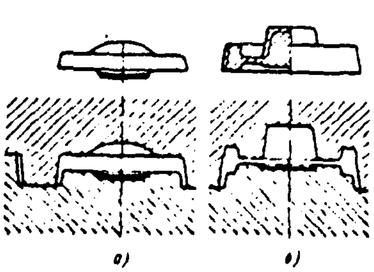

Fig. 23.

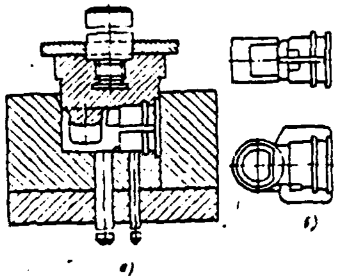

Fig. 24.

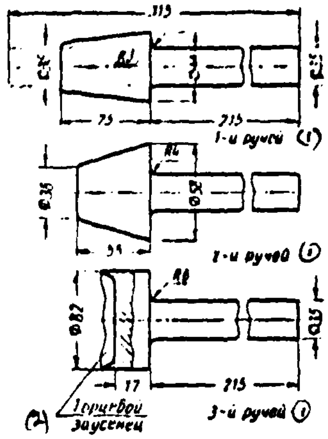

Fig. 25.

Fig. 23. Diagrams of stamping in that closed preliminary (a) and final (b) dies/stamps.

Fig. 24. Diagram of flashless die forging (a) of shaped parts (b).

Fig. 25. Key: (1). groove. (2). End projecting edge.

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2. Upsetting of part with deep piercing in machine 600 T. The blank with a diameter of 55 mm and with a length of 145 mm of the alloy AK6 with the preliminarily drilled hole with a diameter of 8 mm and with a depth of 15 mm under the mount/mandrel is stamped in two

transitions (Fig. 26): in the first groove the blank is upset with the set of collar, the secondly - is accomplished/realized the piercing with the final shaping of stamping.

3. Stamping part of type of sleeve/beaker with blind hole and central extension in machine 600 T. They stamp the blank with a diameter of 80 mm, with a length of 76 mm of the alloy AK6 with the preliminarily drilled hole under the mandrel in two transitions (Fig. 27): in the first groove is upset the collar, the secondly the final shaping of stamping by piercing with the extrusion of metal to the male die/punch.

For titanium alloys the set of metal most frequently is produced in 2-4 transitions during stamping of parts of the type of rod with the boss, when the relationship/ratio of the length of the upset rod to the height/altitude of the upset part composes 1:4+1:8 (Fig. 28), also, in one transition with relationship/ratio 1:2 and less.

Besides upsetting on the GKM, it is possible to perform the operations of bending, narrowing, piercing for forming of blind cavities, gap for obtaining of open-end holes, extrusion, etc.

Table 30 gives the most widely used series/row of GKI with the indication of two forms of the designation of the size/dimension of machines and corresponding conditional number accepted.

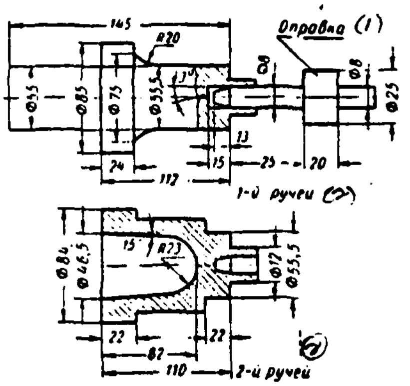

Fig. 26.

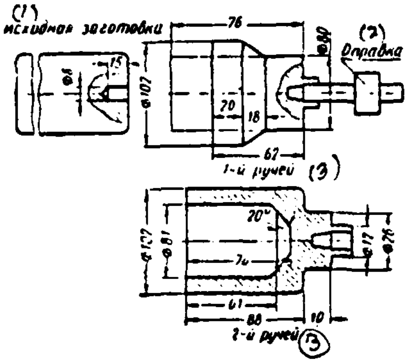

Fig. 27.

Fig. 26. Key: (1). Mount/mandrel. (2). groove.

Fig. 27. Key: (1). Initial blank. (2). Mount/mandrel. (3). groove.

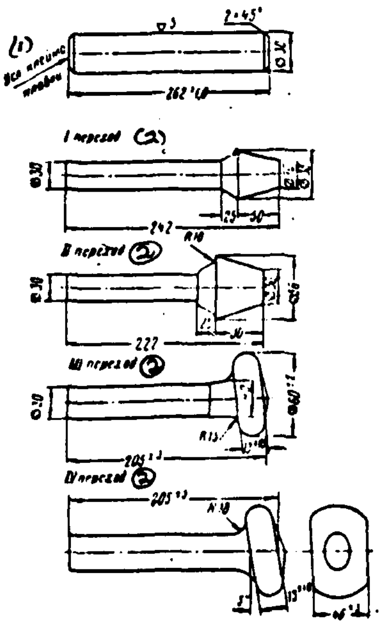

Fig. 28. Technological process of stamping on GKM - upsetting.

Key: (1). Arbitrary mark of melting. (2). transition.

30. Most widely used series/row of GKM.

(1) Условный номер (в дюймах)	(2) Обозначения ГКМ величиной предельно допустимого давления * в т	(3) Обозначение ГКМ размером диаметра высаживаемого прутка в мм
1	50	25
2	200	50
3	450	75
4	750	100
5	1000	125
6	1300	150
7	2000	175
8 (7 1/2)	2500	200 (188)
9	3000	225

Key: (1). Conditional number (in the inches). (2). Designations of GKM with value of maximum permissible pressure[1] in T.

FOOTNOTE [1]. The pressure of machine is the basic index, according to which is set the admissibility of stamping on it the parts of intended sizes. ENDFOOTNOTE.

(3). Designation of GKM with dimension of diameter of upset rod in mm.

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Stamping with the use/application of high-temperature

thermomechanical working.

For the purpose of an increase in the fatigue and static short-term and prolonged strength properties of titanium alloys (property they are raised by 20-30%) is applied the so-called high-temperature thermomechanical working (VTMO).

Stamping of parts with the use/application of VTMO is recommended for titanium alloys of the type $\alpha+\beta$ (alloys BT3-1, BT6, BT8 and BT9). It consists in the coincidence of the operation of stamping with the subsequent water quenching.

Stamping in this case is produced on the same equipment, as common stamping, but it is more preferable to use a press.

The degree of deformation with VTMO for obtaining the optimum strength and plastic properties must be within limits of 40-50%, and the heating temperature under the deformation - should correpsond to the values given in Table 31. The optimum heating temperature must be on 20-30°C lower than temperature of complete ($\alpha+\beta\rightleftarrows\beta$-transformation).

For obtaining of effect of VTMO and uniform strength and plastic properties in this case the thickness of stamping during the use/application of VTMO due to the low thermal conductivity of

titanium alloys must not exceed 30 mm; initial blank must have a structure, which does not exceed the 5th point of the scale of microstructure (Fig. 29) and the 4th point of the scale of the macrostructure (Fig. 30) of titanium alloys.

Stampings should be cooled in the tank with the running water, whose temperature must be supported within limits of 30-70°C.

Immediately after stamping before the cooling in the water it is necessary to trim flash and to conduct straightening. The time of conducting operations (stamping, trimming flash and straightening) from the moment/torque of removal of blanks from the furnace to the cooling in the water must not exceed 40 s (50 s for the alloy BT3-1). By optimum time it is 30-35 s, also, for the alloy BT3-1 of 40-45 s. Shorter time, especially for the alloy BT3-1, leads to a reduction/descent in the plastic properties (strength it is raised). Longer time leads to a decrease in the strength properties.

After stamping of parts with the use/application of VTMO, they must be subjected aging. The temperature of aging and the holding time during the aging are given in Table 32.

31. The temperature of heating prior to stamping of parts with the use/application of VTMO.

(1) Сплав	(2) Температура нагрева ± 10° С
ВТ3-1 (3) и ВТ6	930
ВТ8 (3) и ВТ9	950

Key: (1). Alloy. (2). Heating temperature by ±10°C. (3). and.

32. Aging temperature and holding time during the use of VTMO.

(1) Сплав	(2) Температура старения в °С	(3) Время старения в ч
ВТ3-1	(4) От 550 до 630	5—2
ВТ6	500	2
ВТ8	(4) От 550 до 570	5—2
ВТ9	570	2

Key: (1). Alloy. (2). Temperature of aging in °C. (3). Time of ag g in h. (3). From — to —.

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Lubrication during the stamping.

During stamping of aluminum and magnesium alloys as the lubrication apply artificial wax, oil with graphite, animal fat and oil steam engine cylinder oil. Good results gives also the complex lubrication of the following composition (in %): 8-25 Pb_3O_4; 10 graphites, 10 talcs and remaining oil "steam engine cylinder oil I".

In this lubrication Pb_3O_4 it can be replaced by stearate of lead in the same quantity.

During stamping of titanium and copper alloys as the lubrications apply petroleum residue and oil with graphite, and also different enamels of glass, etc.

After applying a lubricant onto the wall of cavity is produced the blowout with the compressed air for the purpose of more uniform distribution and for the removal/distance of the excessive lubrication of the die cavity.

Standard technological processes of stamping.

The standard technological processes of stamping are given in Table 33-53.

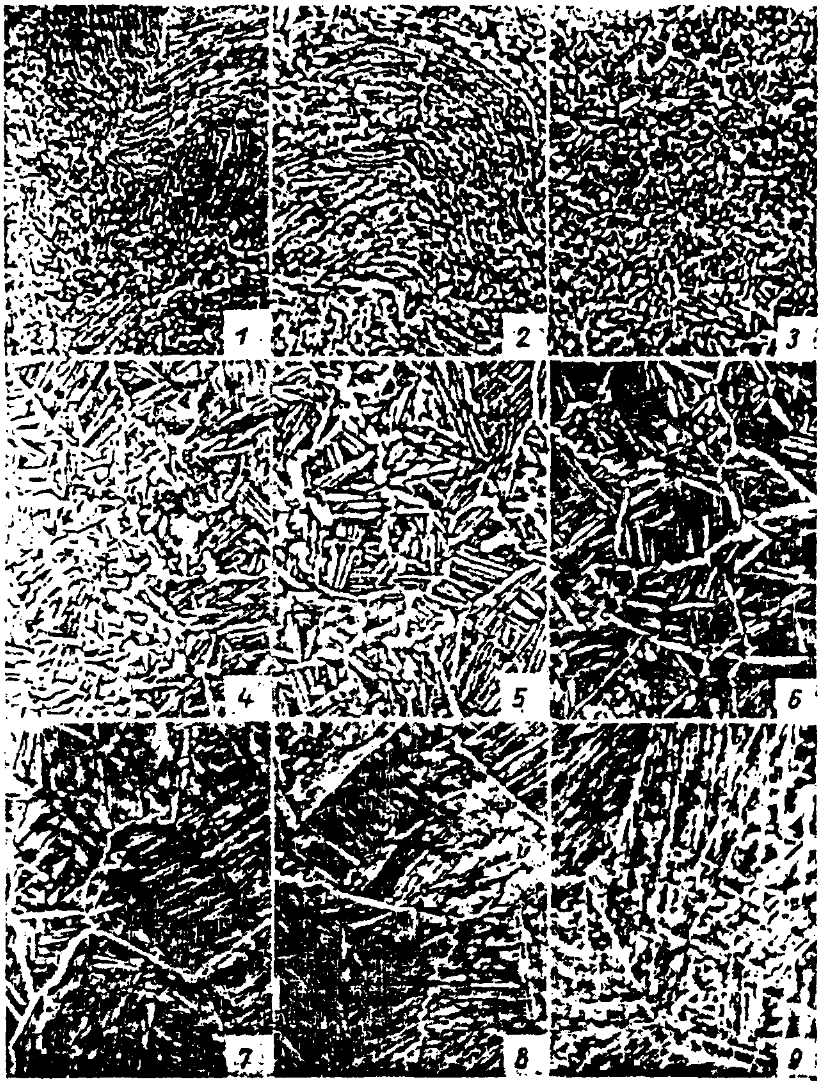

Fig. 29. Scale of the microstructures of titanium alloys.

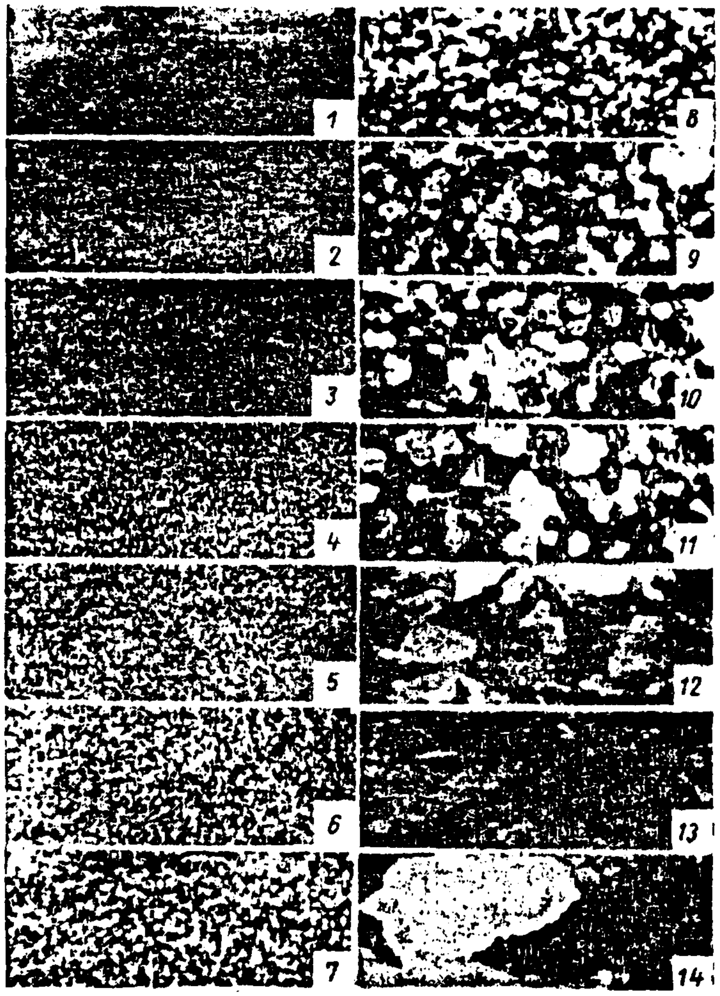

Fig. 30. Scale of macrostructures of titanium alloys.

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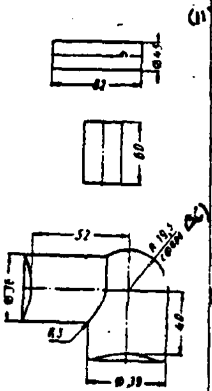
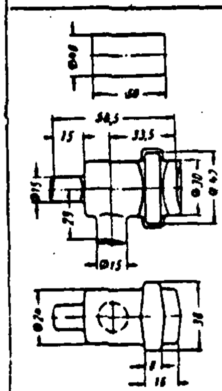
33. Technological process of stamping.

(1) Эскизы переходов	(2) Операция	(3) Температурный режим (4) Время нагрева в мин	(5) Температура в °С (6) начало	(7) конец	(8) Оборудование Инструмент
	(9) Резка заготовок	—	—	—	(10) Дисковая пила
	(11) Промывка заготовок	—	—	—	(12) Моечная машина
	(13) Нагрев	65	—	—	(14) электрическая печь
	(15) Штамповка а) осадка б) в чистовом ручье	—	475	420	(16) Печь. КГШП 630 Т ковочный штамп
	(17) Обрезка облоя	—	—	—	(18) Пресс обрезной 100 Т обрезной штамп
	(19) Травление	—	—	—	(20) Травильные ванны
	(21) Зачистка дефектов	—	—	—	(22) Бормашина
	(13) Нагрев	60	—	—	(14) Электрическая печь
	(23) Калибровка	—	475	420	(24) Печь. КГШП 630 Т калибровочный штамп
	(19) Травление	—	-	—	(20) Травильные ванны
	(21) Зачистка дефектов	—	—	—	(22) Бормашина
	(25) Контроль	—	—	—	—

Key: (1). Drawings/drafts of transitions. (2). Operation. (3). Temperature conditions. (4). Heating time in min. (5). Temperature in °C. (6). beginning. (7). end. (8). Equipment. Instrument. (9). Cutting blanks. (10). Circular saw. (11). Washing of blanks. (12). Washing machine. (13). Heating. (14). Electrical. (15). Stamping. a) upsetting; b) in the finishing groove. (16). Furnace КГШП 630 T, forging die. (17). Trimming flash. (18). Press of trimming 100 T, trimming die. (19). Etching. (20). Etching baths. (21). Trimming of defects/flaws. (22). Drill. (23). Calibration. (24). Furnace КГШП 630 T, calibration. (25). Control. (26). to sphere.

34. Technological process of stamping.

(1) Эскизы переходов	(2) Операция	(3) Температурный режим			(8) Оборудование Инструмент
		(4) Время нагрева в мин	(5) Температура в °С		
			(6) начало	(7) конец	
	(9) Резка заготовок	–	–	–	(10) Дисковая пила
	(11) Промывка заготовок	–	–	–	(12) Моечная машина
	(13) Нагрев	60	–	–	(14) Электрическая печь
	(15) Штамповка	–	480	380	(16) Печь. КГШП 630 Т
	(17) Обрезка облоя	–	–	–	(18) Обрезной пресс 100 Т
	(19) Травление	–	–	–	(20) Травильные ванны
	(21) Зачистка дефектов	–	–	–	(22) Бормашина

Key: (1). Drawings/drafts of transitions. (2). Operation. (3). Temperature conditions. (4). Heating time in min. (5). Temperature in °C. (6). beginning. (7). end. (8). Equipment. Instrument. (9). Cutting blanks. (10). Circular saw. (11). Washing of blanks. (12). Washing machine. (13). Heating. (14). Electric furnace. (15). Stamping. (16). Furnace КГШП 630 T. (17). Trimming flash. (18). Trimming press 100 T. (19). Etching. (20). Etching baths. (21). Trimming of defects/flaws. (22). Drill.

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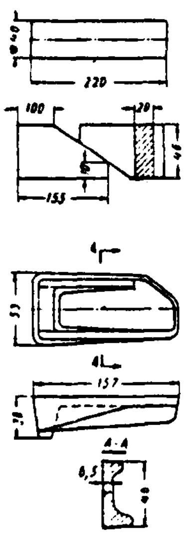
35. Technological process of stamping.



(1) Эскизы переходов	(2) Операция	(3) Температурный режим			(8) Оборудование. Инструмент
		(4) Время нагрева в мин	(5) Температура в °C		
			(6) начало	(7) конец	
	(9) Резка заготовок	—	—	—	(10) Дисковая пила
	(11) Нагрев	60	—	—	(12) Электрическая печь
	(13) Ковка	—	480	380	(14) Ковочный молот 500 кГ
	а) протяжка на квадрат				
	б) разрубка				
	(15) Травление	—	—	—	(16) Травильные ванны
	(17) Зачистка дефектов	—	—	—	(18) Бормашина
	(11) Нагрев	60	—	—	(12) Электрическая печь
	(19) Штамповка предварительная	—	480	380	(20) КГШП 160 Т ковочный штамп
	(21) Обрезка облоя	—	—	—	(22) Обрезной пресс 150 Т
	(15) Травление	—	—	—	(23) Обрезной штамп (16) Травильные ванны
	(24) Зачистка дефектов	—	—	—	(25) Бормашина
	(11) Нагрев	60	—	—	(12) Электрическая печь
	(26) Штамповка окончательная	—	480	380	(20) КГШП 160 Т ковочный штамп
	(21) Обрезка облоя	—	—	—	(22) Обрезной пресс 150 Т
	(15) Травление	—	—	—	(16) Травильные ванны
	(17) Зачистка дефектов	—	—	—	(18) Бормашина
	(27) Контроль	—	—	—	—

Key: (1). Drawings/drafts of transitions. (2). Operation. (3). Temperature conditions. (4). Heating time in min. (5). Temperature in °C. (6). beginning. (7). end. (8). Equipment. Instrument. (9). Cutting blanks. (10). Circular saw. (11). Heating. (12). Electric furnace. (13). Forging. a) broach to the square; b) chopping. (14). Swage 500 kgf. (15). Etching. (16). Etching baths. (17). Trimming of defects/flaws. (18). Drill. (19). Stamping, preliminary. (20). forging die. (21). Trimming flash. (22). Trimming press 150 T. (23). Trimming die. (24). Trimming of defects/flaws. (25). Drill. (26). Stamping, final. (27). Control.

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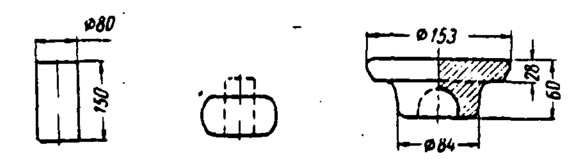
36. Technological process of forging parts from magnesium alloy MA2 on swaging hammer.



а) б) b) в) c)

(1) Операция	(2) Температурный режим			(7) Оборудование Инструмент
	(3) Температура в °С			
	(4) время нагрева	(5) начало операции	(6) конец операции	
(8) Резка заготовки (эскиз а)	—	—	—	(9) Пила
(10) Нагрев заготовки	(10а) 2 ч	420		(11) Электропечь
(12) Осадка в торец (эскиз б)	—	420	300	(13) Молот 1,5 Т Бойки
(14) Нагрев под штамповку	(14а) 1 ч 40 мин	420		Электропечь (11)
Штамповка (эскиз в) (15)	—	420	350	Молот 2,0 Т. Штампы (16)
Обрезка облоя (17)	—	300	250	Пресс 100 Т. Матрица и пуансон (18)
Травление (19)	—	—	—	Ванна (20)
Зачистка дефектов (21)	—	—	—	Бормашина. Фрезы (22)
Травление (19)	—	—	—	Ванна (20)
Оксидирование (23)	—	—	—	
Контроль и сдача (24)	—	—	—	—

(25) Размер заготовки в мм	(26) Вес в кг		(29) Выход годного в %	(30) Примечание
	(27) заготовки	(28) поковки		
D = 80; l = 150	1,40	1,25	74	(31) Температура штампов не менее 250° С. Смазка — машинное масло

Key: (1). Operation. (2). Temperature conditions. (3). Temperature in °C. (4). heating time. (5). beginning of operation. (6). end of operation. (7). Equipment. Instrument. (8). Cutting blank (drawing/draft a). (9). Saw. (10). Heating blank. (10a). h. (11). Electric furnace. (12). upsetting into end/face (drawing/draft b). (13). Hammer 1.5 T. Faces. (14). Heating prior to stamping. (14a). 1 h of 40 min. (15). Stamping (drawing/draft c). (16). Hammer 2.0 T. Dies. (17). Trimming flash. (18). Press 100 T. Die and male die/punch. (19). Etching. (20). Bath. (21). Trimming of defects/flaws. (22). Drill. Milling cutters. (23). Oxidizing. (24). Control and delivery. (25). Size/dimension of blank in mm. (26). Weight in kgf. (27). blank. (28). forging. (29). Yield of suitable in %. (30). Note. (31). Temperature of dies is not less than 250°C. Lubrication - machine oil.

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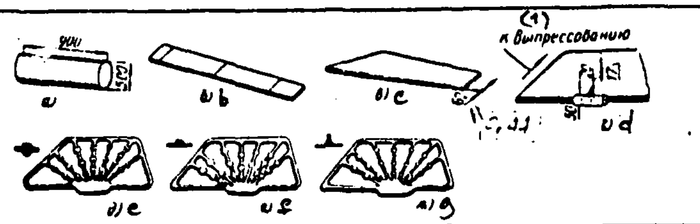
37. Technological process of stamping part (weight of 30 kgf) from alloy MA2-1 on hydraulic press.



(2) Операция	(3) Температурный режим		(5) Оборудование. Инструмент
	(4) Время в ч	° С	
Мерный слиток диаметром 500 × 900 мм (эскиз а) (6)	—	—	—
Гомогенизация слитка (7)	24	390—405	Колодцы (8)
Нагрев (9)	8	300—370	Электропечь (10)
Прессование (эскиз б) (11)	—	370—280	Горизонтальный пресс. Контейнер ⌀ 520 мм. Матрица 62 × 295 (12)
Раскрой заготовки (эскиз в) (13)	—	—	Ленточная пила (14)
Нагрев (9)	1	320—380	Электропечь (10)
Выпрессовка заготовки (эскиз г) (15)		380—300	Вертикальный пресс. Выпрессовочный штамп (16)
Зачистка заготовки (17)	—	—	Бормашина (18)
Нагрев (9)	1	320—380	Электропечь (10)
Заготовительная штамповка (эскиз д) (19)	—	380—300	Вертикальный пресс. Заготовительный штамп (20)
Обрезка облоя, зачистка и травление (21)	—	—	Ленточная пила. Ванна. (22)
Нагрев (9)	1	320—380	Электропечь (10)
Предварительная штамповка (эскиз е) (23)	—	380—300	Вертикальный пресс. Предварительный штамп (24)
Обрезка облоя, зачистка и травление (21)	—	—	Ленточная пила. Ванна (22)
Нагрев (9)	1	320—380	Электропечь (10)
Окончательная штамповка I (эскиз ж) (25)	—	380—300	Вертикальный пресс. Чистовой штамп (26)
Обрезка облоя, зачистка и травление (21)	—	—	Ленточная пила. Ванна (22)
Нагрев (9)	1	320—380	Электропечь (10)
Окончательная штамповка II (эскиз ж) (28)	—	380—300	Вертикальный пресс. Окончательный штамп (29)
Обрезка облоя, зачистка, травление и оксидирование (24)	—	—	Ленточная пила. Ванна (22)
Контроль и сдача (9)	—	—	—

Key: (1). To the extrusion. (2). Operation. (3). Temperature conditions. (4). Time in h. (5). Equipment. Instrument. (6). Measured ingot with diameter of 500×900 mm (drawing/draft a). (7). Homogenization of ingot. (8). Wells. (9). Heating. (10). Electric furnace. (11). extrusion/pressing (drawing/draft b). (12). Horizontal press. Container Ø of 520 mm. Matrix/die 62×295. (13). Layout of blank (drawing/draft c). (14). saw band. (15). Overflow of blank (drawing/draft d). (16). Vertical press. Squeezing-out die/stamp. (17). Trimming of blank. (18). Drill. (19). Preparing stamping (drawing/draft e). (20). Vertical press. Preparing die/stamp. (21). Trimming flash, trimming and etching. (22). Saw band. Bath. (23). preliminary stamping (drawing/draft f). (24). Vertical press. Preliminary die/stamp. (25). Final stamping I (drawing/draft g). (26). Vertical press. The finisher. (27). Final stamping II (drawing/draft g). (28). Vertical press. Final die/stamp. (29). Trimming flash, trimming, etching and oxidizing.

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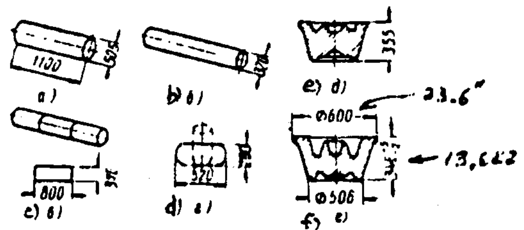
38. Standard technological process of stamping parts (weight of 100 kgf) from alloy BM65-1 on hydraulic presses with a force of 12-15 thousand T.



(1) Операция	(2) Температурный режим (3) Время в ч	°C	(4) Оборудование. Инструмент
(5) Литая заготовка после обточки (эскиз а)	—	—	(6) Токарный станок
(7) Гомогенизация	12	380—400	(8) Электропечь
Нагрев (9)	5	300—350	»
Прессование (степень деформации 62%) (эскиз б) (10)	—	350—300	Горизонтальный пресс. Контейнер ⌀ 540 мм. Матрица ⌀ 320 мм (11)
Резка в меру (косина реза не более 5 мм) (эскиз в) (12)	—	—	Дисковая пила (13)
Обточка с ⌀ 320 мм на ⌀ 310 мм (14)	—	—	Токарный станок (6)
Зачистка острых кромок и торцов (15)	—	—	Бормашина (16)
Нагрев (9)	3	380—420	Электропечь (8)
Осадка (степень деформации) 65%) (эскиз г) (17)	—	420—300	Вертикальный пресс (18)
Зачистка дефектов (19)	—	—	Бормашина (16)
Нагрев (9)	4	300—330	Электропечь (8)
Предварительная штамповка (эскиз д) (20)	—	330—300	Вертикальный пресс, предварительный штамп (21)
Обрезка облоя (22)	—	—	Ленточная пила (22a)
Травление и зачистка дефектов (23)	—	—	Ванна (24)
Нагрев (9)	2	300—330	Электропечь (8)
Окончательная штамповка (эскиз е) (25)	—	330—300	Вертикальный пресс, окончательный штамп (26)
Обрезка облоя (22)	—	—	Ленточная пила (22a)
Термообработка (27)	24	165 ± 5	Колодцы старения (28)
Травление, зачистка и оксидирование (29)	—	—	Ванны (24)
Контроль и сдача (30)	—	—	—

Key: (1). Operation. (2). Temperature conditions. (3). Time in h. (4). Equipment. Instrument. (5). Casting after machining (drawing a). (6). Lathe. (7). Homogenization. (8). Electric furnace. (9). Heating. (10). Extrusion/pressing (degree of deformation 62%) (drawing/draft b). (11). Horizontal press. Container Ø of 540 mm. Matrix/die Ø of 320 mm. (12). Cutting into measure (slant of cut not more than 5 mm) (drawing/draft c). (13). Circular saw. (14). Machining with Ø of 320 mm to Ø of 310 mm. (15). Trimming of sharp edges and ends/faces. (16). Drill. (17). Upsetting (degree of deformation 65%) (drawing/draft d). (18). Vertical press. (19). Trimming of defects/flaws. (20). Preliminary stamping (drawing/draft e). (21). Vertical press, preliminary die/stamp. (22). Trimming flash. (22a). Saw band. (23). Etching and trimming of defects/flaws. (24). Bath. (25). Final stamping (drawing/draft c). (26). Vertical press, final die/stamp. (27). Heat treatment. (28). Wells of aging. (29). Etching, trimming and oxidizing. (30). Control and delivery.

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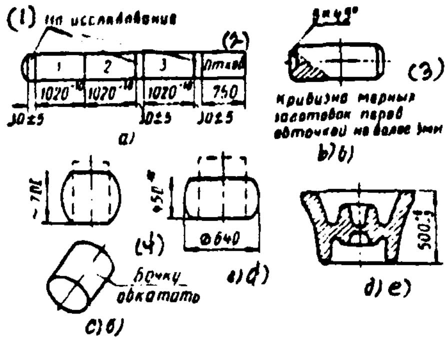
39. Technological process of stamping parts (weight of 230 kgf) from alloy BM65-1 on hydraulic presses.



(5) Операции	(6) Температурный режим (7) Время нагрева в ч	(8) Температура в °C (9) начала операции	(10) окончания операции	(11) Оборудование. Инструмент
Гомогенизация (12)	12	380—400		Колодцы (13)
Обточка слитка с Ø 670 на Ø 630 + 2 мм (14)	—	—	—	Токарный станок (15)
Нагрев под прессование (16)	5,5	280—320		Электропечь (17)
Прессование (18)	—	310	280	Горизонтальный пресс. Контейнер Ø 650 мм. Матрица Ø 420 мм (19)
Резка в меру (косина реза до 10 мм) (эскиз а) (20)	—	—	—	Дисковая пила (21)
Обточка заготовки с Ø 420 ± 2 на Ø 400 ± 1 мм (22)	—	—	—	Токарный станок (15)
Зачистка центров и острых кромок (эскиз б) (23)	—	—	—	Бормашина (24)
Нагрев под ковку (25)	3,5	380—420		Электропечь (17)
Осадка (эскиз в) (26)	—	420	300	Вертикальный пресс (27)
Зачистка дефектов (28)	—	—	—	Бормашина (24)
Нагрев (29)	3,5	350—380		Электропечь (17)
Предварительная штамповка (30)	—	380	300	Вертикальный пресс. Предварительный штамп (31)
Обрезка облоя (32)	—	—	—	Карусельный станок (33)
Травление и зачистка (34)	—	—	—	Ванна и бормашина (35)
Нагрев (29)	2,0	300—330		Электропечь (17)
Окончательная штамповка I (эскиз в) (36)	—	330	280	Вертикальный пресс (27)
Обрезка облоя (32)	—	—	—	Карусельный станок (33)
Травление, зачистка дефектов (37)	—	—	—	Ванна и бормашина (35)
Нагрев (29)	1,5	300—330		Электропечь (17)
Окончательная штамповка II (эскиз д) (38)	—	330	280	Вертикальный пресс (27) Окончательный штамп (39)
Обрезка облоя (32)	—	—	—	Карусельный станок (33)
Термообработка-старение (40)	24	105 ± 5		Колодцы старения (41)
Травление и зачистка дефектов (42)	—	—	—	Ванна и бормашина (35)
Оксидирование (43)	—	—	—	Ванна (44)
Контроль и сдача (45)	—	—	—	—

Key: (1). for investigation. (2). Withdrawal/departure. (3). Curvature of gaging blanks of vapors of machining of not more than 3 mm. (4). Turning the barrel. (5). Operation. (6). Temperature conditions. (7). Time of heating in h. (8). Temperature in °C. (9). beginning of operation. (10). finishing of operation. (11). Equipment. Instrument. (12). Homogenization. (13). Wells. (14). Machining of ingot with Ø 670 on Ø of 630+2 mm. (15). Lathe. (16). Heating for extrusion. (17). Electric furnace. (18). Extrusion/pressing. (19). Horizontal press. Container Ø of 650 mm. Matrix/die Ø of 420 mm. (20). Cutting into measure (slant of cut to 10 mm) (drawing/draft a). (21). Circular saw. (22). Machining of blank Ø 420±2 on Ø 400±1 mm. (23). Trimming of centers and sharp/acute. (24). Drill. (25). Heating for forging. (26). Upsetting (drawing/draft c). (27). Vertical press. (28). Trimming of defects/flaws. (29). heating. (30). Preliminary stamping. (31). Vertical press. Preliminary die/stamp. (32). Trimming flash. (33). vertical turret lathe. (34). Etching and trimming. (35). Bath and drill. (36). Final stamping I (drawing/draft d). (37). Etching, trimming of defects/flaws. (38). Bath and drill. (38a). Final stamping II (drawing e). (39). Final die/stamp. (40). Heat treatment-aging. (41). Wells of aging. (42). Etching and trimming of defects/flaws. (43). Oxidizing. (44). Bath. (45). Control and delivery.

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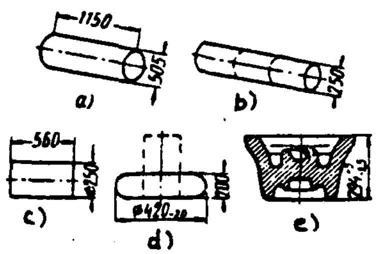
40. Standard technological process of stamping parts (weight of 60 kg) from alloy MA5 on hydraulic press.



(1) Операция	(2) Температурный режим: Время нагрева в ч (3)	(4) Температура в °C: начала операции (5)	окончания операции (6)	Оборудование. Инструмент (7)
(8) Гомогенизация слитка (эскиз а):				
I ступень (9)	6	350—370		Колодезные печи (10)
II ступень	8	380—400		То же (11)
Нагрев под прессование (12)	5	300—400		Электропечь (13)
Прессование (коэффициент вытяжки — 4) (эскиз б) (14)	—	330	300	Горизонтальный пресс. (15) Контейнер ⌀ 540 мм. Матрица ⌀ 262 мм
Резка в меру (16)	—	—	—	Дисковая пила (17)
Обточка заготовки (18) с ⌀ 60 ± 2 мм на ⌀ 250 ± 1 мм (эскиз в)	—	—	—	Токарный станок (19)
Нагрев под ковку (20)	2,5	350—380		Электропечь (13)
Осадка (степень деформации 65%) (эскиз в) (21)	—	380	300	Вертикальный пресс (22)
Зачистка дефектов (23)	—	—	—	Бормашина (24)
Нагрев под штамповку (эскиз д) (25)	1,5	350—380		Электропечь (13)
Предварительная штамповка (26)	—	380	300	Вертикальный пресс. (27) Предварительный штамп
Обрезка облоя (28)	—	—	—	Ленточная пила (29)
Травление и зачистка дефектов (30)	—	—	—	Травильная ванна и бормашина (31)
Нагрев (32)	1,0	320—350		Электропечь (13)
Окончательная штамповка (33)	—	350	300	Вертикальный пресс. (34) Окончательный штамп.
Обрезка облоя (28)	—	—	—	Ленточная пила (29)
Термообработка, старение (35)	24	185 ± 5		Электропечь старения (36)
Травление, зачистка дефектов, оксидирование (37)	—	—	—	Ванна (38)
Контроль и сдача (39)	—	—	—	—

Key: (1). Operation. (2). Temperature conditions. (3). Heating time in h. (4). Temperature in °C. (5). beginning of operation. (6).

termination of operation. (7). Instrumentation. (8). Homogenization of ingot (drawing/draft a). (9). step/stage. (10). Soaking pits. (11). The same. (12). Heating for extrusion. (13). Electric furnace. (14). Extrusion/pressing (coefficient of drawing - 4) (drawing/draft b). (15). Horizontal press. Container Ø 540 mm. Matrix/die Ø of 262 mm. (16). Cutting into measure. (17). Circular saw. (18). Machining of blank on (drawing/draft c). (19). Lathe. (20). Heating for forging. (21). Upsetting (degree of deformation 65%) (drawing/draft d). (22). Vertical press. (23). Trimming of defects/flaws. (24). Drill. (25). Heating prior to stamping (drawing/draft e). (26). Preliminary stamping. (27). Vertical press. Preliminary die/stamp. (28). Trimming flash. (29). Saw band. (30). Etching and cleaning of defects/flaws. (31). Etching bath and drill. (32). Heating. (33). Final stamping. (34). Vertical press. Final die/stamp. (35). Heat treatment, aging. (36). Electric furnace of aging. (37). Etching, trimming of defects/flaws, oxidizing. (38). Bath. (39). Control and delivery.

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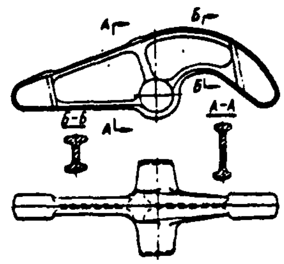
41. Standard technological process of stamping part from alloy BM65-1 on crank press.

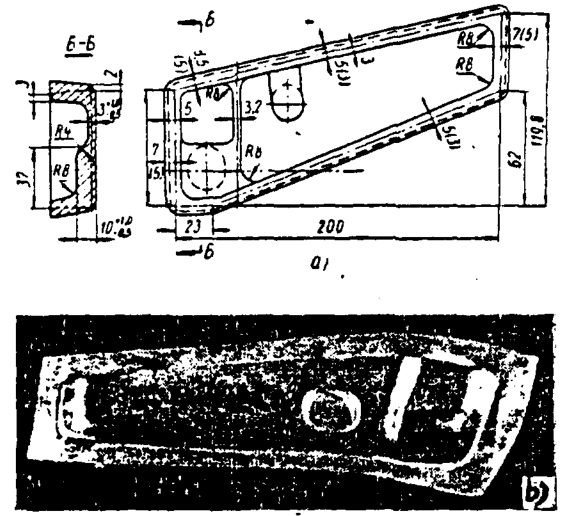


(1) Операция	(2) Температурный режим			(7) Оборудование. Инструмент
	(3) Время нагрева	(4) Температура в °C		
		(5) начала операции	(6) окончания операции	
(8) Резка мерных заготовок (прессованный пруток) ⌀ 60×205 мм	—	—	—	(9) Ленточная пила
(10) Нагрев	(11) 1 ч 30 мин	400—300		(12) Электропечь ПН-15
(13) Предварительная штамповка	—	400	300	(14) Кривошипный пресс 2000 Т. Окончательный штамп
(15) Обрезка облоя	—	—	—	(16) Пила
(10) Нагрев	(11) 1 ч 30 мин	380—300		(12) Электропечь ПН-15
(17) Окончательная штамповка	—	380	320	(14) Кривошипный пресс 2000 Т. Окончательный штамп
(15) Обрезка облоя	—	300—280		(18) Обрезной пресс
(19) Травление	—	—	—	(20) Ванны
(21) Зачистка дефектов	—	—	—	(22) Бормашина
(23) Травление и оксидирование	—	—	—	(20) Ванны
(24) Контроль и сдача	—	—	—	—

Key: (1). Operation. (2). Temperature conditions. (3). Heating time. (4). Temperature in °C. (5). beginning of operation. (6). termination

of operation. (7). Equipment. Instrument. (8). Cutting measured blanks (pressed rod). (9). Saw band. (10). Heating. (11). 1 h, 30 min. (12). Electric furnace ПН-15. (13). Preliminary stamping. (14). Crank press 2000 T. Final die/stamp. (15). Trimming flash. (16). Saw. (17). Final stamping. (18). Trimming press. (19). Etching. (20). Bath. (21). Trimming of defects/flaws. (22). Drill. (23). Etching and oxidizing. (24). Control and delivery.

42. Standard technological process of stamping the parts from alloy BM65-1 on the crank press.



(1) Операция	(2) Температурный режим			(7) Оборудование Инструмент
	(3) Время нагрева	(4) Температура °C		
		(5) начала операции	(6) окончания операции	
(8) Резка заготовок из полосы толщиной 25×78×213 мм	—	—	—	(9) Ленточная пила
Нагрев (10)	(11) 1 ч 20 мин	400	350	(12) Электропечь ПН-15
(13) Предварительная штамповка	—	400	300	(14) Кривошипный пресс 1500 Т Окончательный штамп
(15) Обрезка облоя	—	—	—	Ленточная пила (9)
Нагрев (10)	(11) 1 ч 20 мин	380	300	Электропечь ПН-15 (12)
(16) Окончательная штамповка	—	380	320	Кривошипный пресс 1500 Т (14) Окончательный штамп
(15) Обрезка облоя	—	300	280	Обрезной пресс (17)
Травление (18)	—	—	—	Ванна (19)
Зачистка дефектов (20)	—	—	—	Бормашина (21)
Травление и оксидирование (22)	—	—	—	Ванны (19)
Контроль и сдача (23)	—	—	—	—

Key: (1). Operation. (2). Temperature conditions. (3). Heating time. (4). Temperature of °C. (5). beginning of operation. (6). termination of operation. (7). Equipment. Instrument. (8). Cutting blanks of band with thickness of 25×78×213 mm. (9). Saw band. (10). Heating. (11). 1 h, 20 min. (12). Electric furnace ПН-15. (13). Preliminary stamping. (14). Crank press 1500 T. Final die/stamp. (15). Trimming flash. (16). Final stamping. (17). Trimming press. (18). Etching. (19). Bath. (20). Trimming of defects/flaws. (21). Drill. (22). Etching and oxidizing. (23). Control and delivery.

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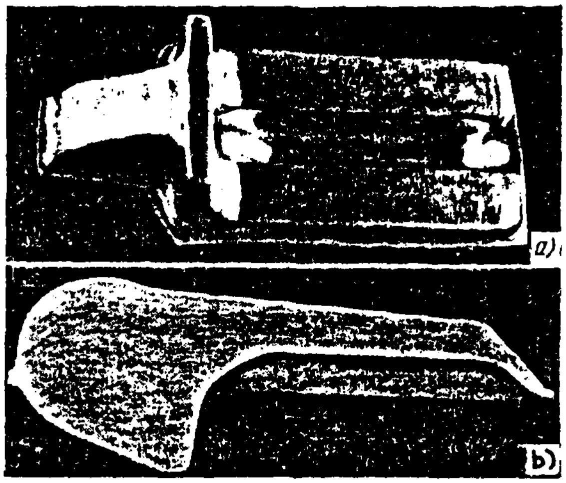
43. Standard industrial process of stamping part on alloy BM65-1 on crank press.



(1) Операция	(2) Температурный режим			(7) Оборудование. Инструмент
	(3) Время нагрева	(4) Температура в °C		
		(5) начала операции	(6) окончания операции	
(8) Резка заготовки из полосы толщиной 35 *мм*	—	—	—	(9) Пила
(10) *Нагрев*	(11) 1 ч 20 *мин*	400	350	(12) Электропечь ПН-15
(13) Предварительная штамповка	—	400	300	(14) Кривошипный пресс *1600 Т.* Окончательный штамп
(15) Обрезка облоя	—	—	—	(16) Ленточная пила
(10) Нагрев	(11) 1 ч 20 *мин*	380	300	(12) Электропечь ПН-15
(17) Окончательная штамповка	—	380	320	(18) Кривошипный пресс 1600 *Т.* Окончательный штамп
(15) *Обрезка облоя*	—	300	280	(19) Обрезной пресс
(20) Травление	—	—	—	(21) Ванна
(22) Зачистка дефектов	—	—	—	(23) Бормашина
(24) Травление и оксидирование	—	—	—	Ванны (21)
(25) Контроль и сдача	—	—	—	—

Key: (1). Operation. (2). Temperature mode/conditions. (3). Heating time. (4). Temperature in °C. (5). beginning of operation. (6).

termination of operation. (7). Instrumentation. (8). Cutting blank of band with thickness of 35 mm. (9). Saw. (10). Heating. (11). 1 h, 20 min. (12). Electric furnace ПН-15. (13). Preliminary stamping. (14). Crank press 1500 T. Final die/stamp. (15). Trimming flash. (16). Saw band. (17). Final forging. (18). Crank press 1500 T. Final die/stamp. (19). Trimming press. (20). Etching. (21). Bath. (22). Trimming of defects/flaws. (23). Drill. (24). Etching and oxidizing. (25). Control and delivery.

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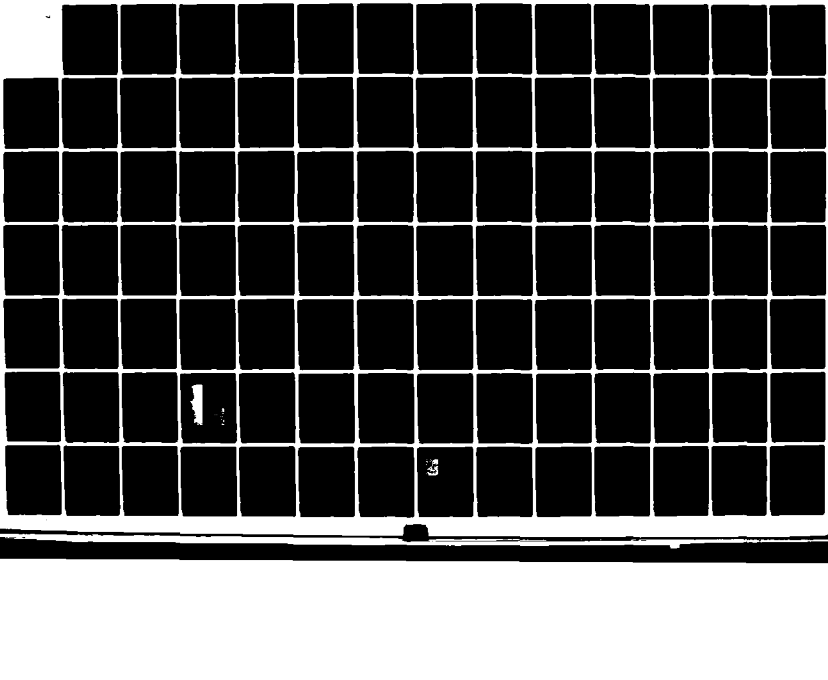

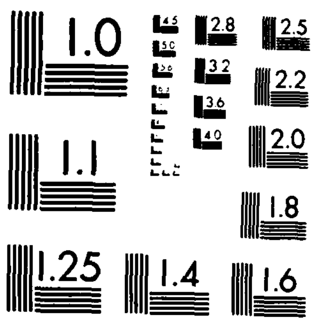

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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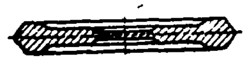
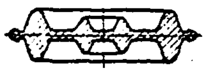
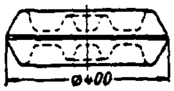
44. Technological process of stamping disk on titanium alloy (during stamping it predominates settling) (I group).

(1) Эскиз операции	(2) Операция	(3) Оборудование
	(4) Заготовка шайбы (получена методом двух-, трехкратной осадки-протяжки)	—
	(5) Нагрев	(6) Печь
	J_m = 0.039 мм	
	(7) Штамповка	(8) Молот 16 Т или пресс 15—20 тыс. Т
	(9) Обрезка облоя	(10) Обрезной пресс 600—800 Т
	(11) Правка	(8) Молот 16 Т или 15—20 тыс. Т
—	(12) Зачистка дефектов	—

Key: (1). Drawing/draft of operation. (2). Operation. (3). Equipment. (4). Blank of washer (it is obtained by method two-, three-fold upsetting-drawing). (5). Heating. (6). Furnace. (7). Stamping. (8). Hammer 16 T or press 15-20 thousand T. (9). Trimming flash. (10). Trimming press 600-800 T. (11). Straightening. (12). Trimming of defects/flaws.

45. The technological process of stamping the disk from titanium alloy (during the stamping it predominates extrusion) (I group).

(1) Эскиз перехода	(2) Операция	(3) Оборудование
	(4) Нагрев	(5) Печь
	(6) Штамповка а) переход предварительный (8) Нагрев б) переход окончательный	(7) Молот 10 *T* или пресс 10 тыс. *T*
	(9) Обрезка облоя	(10) Обрезной пресс 600 *T*
	(11) Правка	

Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment. (4). Heating. (5). Furnace. (6). Stamping. a) transition, preliminary. (7). Hammer 10 T or press 10 thousand T. (8). Heating. b) transition, final. (9). Trimming flash. (10). Trimming press 600 T. (11). Straightening.

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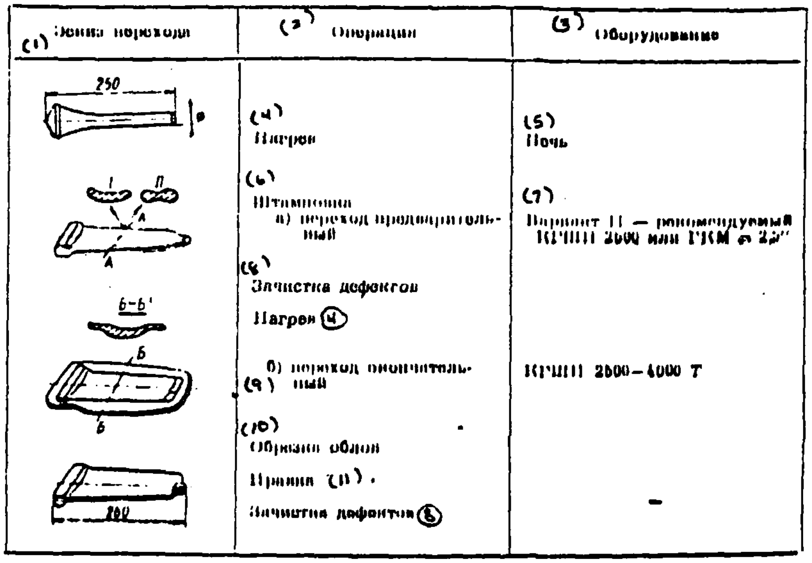
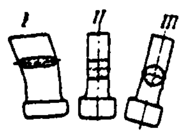
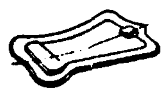
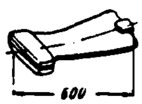
46. Technological process of stamping blades from titanium alloy (II group).



Key: (1). Drawing/draft of transition. (2). Operations. (3). Equipment. (4). Heating. (5). Furnace. (6). Stamping a) transition, preliminary. (7). Version II - recommended die-forging crank press 2500 or GKM52.5". (8). Trimming of defects/flaws. (9). b) transition is final. (10). Trimming of seam. (11). Straightening.

47. Technological process of stamping the large-scale blades from titanium alloy (II group).

(1) Эскиз перехода	(2) Операции	(3) Оборудование
	(4) Фасонная заготовка (получена методом двух-, трехкратной осадки-протяжки)	—
	Нагрев (5)	Печь (6)
	Штамповка (7)	(8) Молот 13–15 Т или пресс 8 000–10 000 Т
	Обрезка облоя (9)	(10) Обрезной пресс 1000–1200 Т
 	(11) Правка	—
	(12) Зачистка дефектов	—

Key: (1). Drawing/draft of transition. (2). Operations. (3). Equipment. (4). Shaped blank (it is obtained by method of two-, triple upsetting-broach). (5). Heating. (6). Furnace. (7). Stamping. (8). Hammer 13-15 T or press 8000-10000 T. (9). Trimming flash. (10). Trimming press 1000-1200 T. (11). Straightening. (12). Trimming of defects/flaws.

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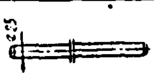
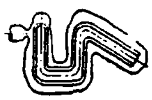
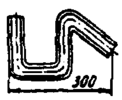
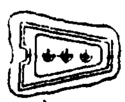
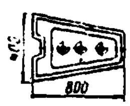
48. Technological process of stamping parts of type of fork-bracket from titanium alloy (III group).

Эскиз перехода (1)	Операция (2)	Оборудование (3)
	Нагрев (4)	Печь (5)
	Штамповка (6) а) переход предварительный — гибка	Молот 1 Т (7)
	Нагрев (8) б) переход окончательный	Печь (9) Молот 1 Т или пресс 2500 Т
	Обрезка облоя (10)	Обрезной пресс 200—300 Т (11)
	Правка (12)	—
	Зачистка заусенцев (13)	—

Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment. (4). Heating. (5). Furnace. (6). Stamping a) transition preliminary - bending. (7). Jetty 1 T. (8). Heating b) transition, final. (9). Furnace. Hammer 1 T or press 2500 T. (10). Trimming flash. (11). Trimming press 200-300 T. (12). Straightening. (13). Deburring.

49. Technological process of stamping the frame from titanium alloy (IV group).

Эскиз перехода (1)	Операция (2)	Оборудование (3)
	Нагрев (4)	Печь (5)
	(6) Ковка фасонной заготовки методом двойной осадки-протяжки	(7) Молот 5 Т
	Нагрев (4)	Печь (5)
	(8) Предварительная штамповка	(9) Гидравлический пресс 30 000 Т
	Нагрев (4)	Печь (5)
	Окончательная штамповка (10)	
	(11) Обрезка облоя	(12) Обрезной пресс 1000 Т
	(13) Правка	(9) Гидравлический пресс 30 000 Т

Key: (1). Drawing/draft of transition. (2). Operation. (3). Equipment. (4). Heating. (5). Furnace. (6). Forging annular billet by method of dual upsetting-broach. (7). Hammer 5 T. (8). Preliminary stamping. (9). Hydraulic press 30000 T. (10). Final stamping. (11). Trimming flash. (12). Trimming press 1000 T. (13). Straightening.

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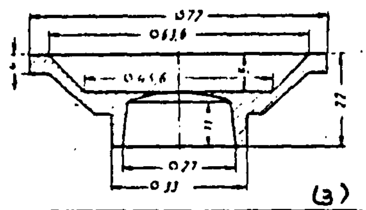
50. Standard technological process of stamping cup from alloy Л-59 on friction press.

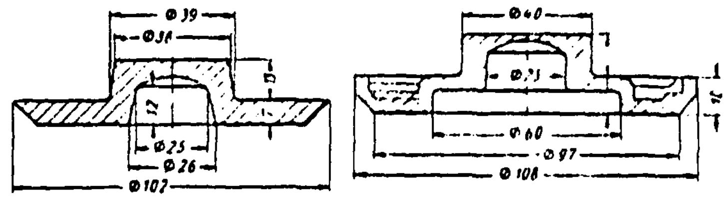


(1) Операция	(2) Оборудование	(3) Температурный режим в °С (4) Начало операции	(5) Конец операции
(6) Резка мерной заготовки 60×7,9 мм[1]	Дисковая пила (7)	—	
(8) Нагрев заготовки	Печь (9)	700	
(10) Штамповка	Фрикционный пресс (11)	780	730
(12) Отпуск	Печь (9)	300	
(13) Травление	Травильные ванны (14)	—	
(15) Контроль и передача на механическую обработку	Контрольный стол (16)	—	

Key: (1). Operation. (2). Equipment. (3). Temperature conditions in °C. (4). Beginning of operation. (5). End of operation. (6). Cutting measured blank 60×7.9 mm[1].

FOOTNOTE [1]. In the absence of rod Ø of 60 mm the blank can be cut of the smaller diameter with the subsequent upsetting to Ø 60 mm. ENDFOOTNOTE. (7). Circular saw. (8). Heating blank. (9). Furnace. (10). Stamping. (11). Friction press. (12). Tempering. (13). Etching. (14). Etching baths. (15). Control and transfer to mechanical working. (16). Monitoring desk.

51. Standard technological process of stamping the limb/dial from the alloy Л-59 on the friction press.



(1) Операция	(2) Оборудование	(3) Температурный режим в °С (4) Начало операции	(5) Конец операции
(6) Резка мерной заготовки 90×10 мм*[1]	Дисковая пила (7)	–	–
(8) Нагрев заготовки	Печь (9)	780	
(10) Предварительная штамповка	Фрикционный пресс (11)	780	730
(12) Подогрев	Печь (9)	780	
(13) Окончательная штамповка	Фрикционный пресс (11)	780	730
(14) Прошивка центрального отверстия** 2	Обрезной пресс (15)	–	–
(16) Отпуск	Печь (9)	800	
(17) Травление	Травильная ванна (18)	–	
(19) Контроль и передача на механическую обработку	Контрольный стол (20)	–	

Key: (1). Operation. (2). Equipment. (3). Temperature conditions in °C. (4). Beginning of operation. (5). End of operation. (6). Cutting measured blank 90×10 mm[1].

FOOTNOTE [1]. In the absence of rod Ø of 90 mm the blank can be cut from rod Ø of 50 mm with the subsequent upsetting to Ø of 90 mm. ENDFOOTNOTE.

(7). Disk saw. (8). Heating blank. (9). Furnace. (10). Preliminary stamping. (11) Friction press. (12). Preheating. (13). Final stamping. (14). Piercing of central hole [2].

FOOTNOTE [2]. Operation is introduced for facilitating the machining. ENDFOOTNOTE.

(15). Trimming press. (16). Tempering. (17). Etching. (18). Etching bath. (19). Control and transmission to machining. (20). Monitoring desk.

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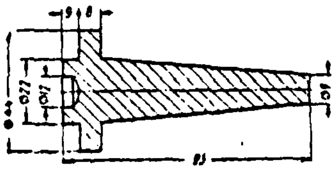
52. Standard technological process of stamping cone from alloy Л-59 on friction press.



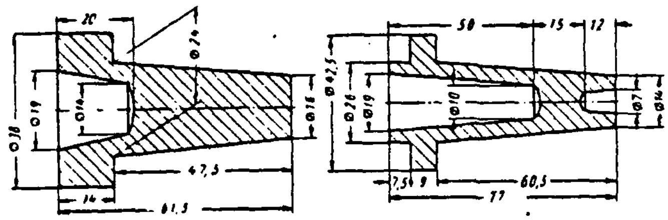
<table>
<tr><th rowspan="2">(1) Операция</th><th rowspan="2">(2) Оборудование</th><th colspan="2">(3) Температурный режим в °C</th></tr>
<tr><th>(4) Начало операции</th><th>(5) Конец операции</th></tr>
<tr><td>(6) Резка мерной заготовки 35×32 мм¹</td><td>Ленточная пила (7)</td><td colspan="2">—</td></tr>
<tr><td>(8) Нагрев заготовки</td><td>Печь (9)</td><td colspan="2">780</td></tr>
<tr><td>(10) Штамповка</td><td>Фрикционный пресс (11)</td><td>780</td><td>730</td></tr>
<tr><td>(12) Отпуск</td><td>Печь (9)</td><td colspan="2">300</td></tr>
<tr><td>(13) Травление</td><td>Травильные ванны (14)</td><td colspan="2">—</td></tr>
<tr><td>(15) Контроль и передача на механическую обработку</td><td>Контрольный стол (16)</td><td colspan="2">—</td></tr>
</table>

Key: (1). Operation. (2). Equipment. (3). Temperature conditions in °C. (4). Beginning of operation. (5). End of operation. (6). Cutting measured blank 35×32 mm [1].

FOOTNOTE [1]. In the absence of rod Ø of 35 mm the blank can be cut from rod Ø of 30 mm. ENDFOOTNOTE.

(7). Band saw. (8). Heating blank. (9). Furnace. (10). Stamping. (11). Friction press. (12). Tempering. (13). Etching. (14). Etching baths. (15). Control and transmission to machining. (16). Monitoring desk.

53. Standard technological process of stamping tanks from the alloy Л-59 on function press.



(1) Операция	(2) Оборудование	(3) Температурный режим в °C	
		(4) Начало операции	(5) Конец операции
(6) Резка мерной заготовки 35×27.8 мм[1]	Ленточная пила (7)	—	
(8) Нагрев заготовки	Нагревательная печь (9)	780	
(10) Предварительная штамповка	Фрикционный пресс (11)	780	730
(12) Подогрев	Нагревательная печь (9)	780	
(13) Окончательная штамповка	Фрикционный пресс (11)	780	730
(14) Отпуск	Нагревательная печь (9)	300	
(15) Травление	Травильная ванна (16)	—	
(17) Контроль и передача на механообработку	Контрольный стол (18)	—	

Key: (1). Operation. (2). Equipment. (3). Temperature conditions in °C. (4). Beginning of operation. (5). End of operation. (6). Cutting measured blank 35×27.8 mm [1].

FOOTNOTE [1]. In the absence of rod Ø ~~of~~ 35 mm the blank can be cut from rod Ø ~~of~~ 30 mm. ENDFOOTNOTE.

(7). Saw band. (8). Heating blank. (9). Reheating furnace. (10). Preliminary stamping. (11). Friction press. (12). Preheating. (13). Final stamping. (14). Tempering. (15). Etching. (16). Etching bath.

(17). Control and transmission to machining. (18). Monitoring desk.

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CALIBRATION.

Planar calibration is accomplished/realized by reduction between the slabs of the separate elements of stamping and is applied for obtaining of precise sizes/dimensions and required purity/finish of separate flat/plane ones and curvilinear irregularities. Planar calibration can also undergo roughly by cut surface of parts. During the planar calibration the free flow of metal in the direction, perpendicular to the displacement/movement of the deforming instrument, occurs.

Reduction can undergo simultaneously two or several surfaces. These surfaces can be located in several parallel planes (Fig. 31a).

To avoid warping/buckling the separate not subjected calibration places of blank, in particular with the considerable distances between the calibrated sections, these places undergo the partial reduction (straightening/trimming).

Volumetric calibration is accomplished/realized via the

reduction of blank in the die impression with the extrusion of excessive metal in the flash (Fig. 31b). Forming flash is trimmmed in a special die/stamp, and it is most frequently removed by machining.

In the process of hot calibration the dies/stamps must have a temperature of 200°C for the massive blanks and 300-350°C for the blanks with thin cloths. The optimum equipment for the hot calibration is hot-stamping presses. This operation is feasible on the single-acting hammers. Function presses and double-acting hammers should not be applied in connection with the danger of a breakage in the stocks/rods or the actuating screws due to the so-called "dry" impacts/shocks. Coining presses should not be applied for the hot calibration, since the thin parts of the blank manage to support in the process of the increase of deforming forces, as a result during the removal/distance of blank of the die/stamp it can obtain additional warping/buckling.

Lubrication during the calibration. For calibrating the blanks of the aluminum alloys are applied the following compositions of lubrications (in %): 60 vaseline of technical; 30 soaps of economic; 10 stearins.

The lubrication, which consists of 75% of fish fat and 25% of stearin, is somewhat less effective.

The use/application of the lubrications indicated decreases the required effort/force of calibration to 8-20%.

One should apply for the calibration the paraffin/kerosene lubrications, which make it possible sometimes to lower specific pressure on 50-60%, providing in this case the alignment/levelling specific pressure on the end/face of article considerably decreasing the convexity of ends/faces.

Steel, utilized for the sizing dies, can resist, by specific pressure on the order of 200-250 kg/mm^2. Alignment/levelling and reduction/descent in the specific pressures will contribute to a considerable increase in the stability of calibrating instrument.

The use/application of paraffin will make it possible to upset the samples/specimens with relationship/ratio d/h=16, whose sediment/residue under the normal conditions it is difficult in the form of high specific pressures and low stability.

The insufficient finish of the calibrated surfaces is an essential shortcoming in the use/application of lubrications. In this respect the calibration without the lubrication, which with a

sufficient surface finish characteristics of block gages gives the surface finish in many instances higher than grinding, has an advantage.

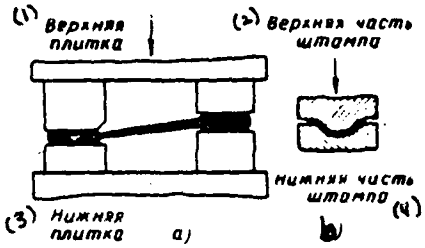

Fig. 31. Key: (1). Upper slab. (2). Upper part of die. (3). Lower slab. (4). Lower part of die.

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The method of dual calibration is very effective.

The first calibration - without the lubrication serves for obtaining clean and smooth butt ends. By this operation is taken by 75% of allowance for calibration. The second calibration is produced with the lubrication and serves for the correction of the convexity of butt ends obtained during the first calibration.

Surface Cleaning of Stampings.

The surface of stampings from the alloys of nonferrous metals is cleaned with etching (Table 54).

54. Compositions of etching solutions.

(1) Материал штамповок	(2) Состав раствора	(3) Темпера-тура раствора в °C	(4) Продол-житель-ность в мин	(5) Назначение
(9) Алюминиевые сплавы	Na_3PO_4 — 50 г Na_2CO_3 — 50 г (6) Жидкое стекло — 30 г (7) Вода — 1 л	60—70	2	(8) Обезжиривание
	NaOH или KOH — (50—70) г (10) Вода — 1 л (7)	40—50	2	(11) Травление
	(12) HNO_3 уд. вес 1,4—1 л Вода — 1 л (7)	(13) Комнатная 15—20	2—5	(14) Осветление
(15) Магниевые сплавы	CrO_3 — 20%-ный раствор (16) HNO_3 — 90—100 г/л, уд. вес 1,4 (12) $K_2Cr_2O_7$ — 70 г/л NH_4Cl — 3—5 г/л	60—80 60—80	3—5 10—20	(11) Травление
	NaOH или KOH — 50—70 г (10) Вода — 1 л (7)	40—50	2—3	(8) Обезжиривание
(17) Титановые сплавы 1	(18) 1 раствор H_2SO_4 — 110—130 г/л + HF — 70—80% г/л	20	0,5—5	(11) Травление
	2 раствор: H_2SO_4 — 180—220 г/л + NF — 35—45 г/л (19)	55—65	10—30	
(19) Бронза Бр.АЖМ	HNO_3 — 1 л., уд. вес 1,4 (12) Вода — 1 л (7)	15—20	2	
(20) Латунь	HNO_3 — 200 см³, уд. вес 1,4 (12) HCl — 2 см³, уд. вес 1,19 Глянцевая сажа — 1 ÷ 2 г (21) Вода — 800 см³ (7)	15—20	3—5	Предварительное травление (22)
	HNO_3 — 75 см³; уд. вес 1,4 (12) H_2SO_4 — 100 см³; уд. вес 1,84 HCl — 1 см³; уд. вес 1,19 (7) Вода — 824 см³	15—20	3—5	(23) Глянцевое травление

Key: (1). Material of stampings. (2). Composition of solution/opening. (3). Temperature of solution/opening in °C. (4). Duration in min. (5). Designation/purpose. (6). Water glass. (7). Water. (8). Degreasing. (9). Aluminum alloys. (10). or. (11). Etching. (12). ud weight. (13). Room. (14). Bright dipping. (15). Magnesium alloys. (16). 20%solution. (17). Titanium alloys [1].

FOOTNOTE [1]. Scale on the surface of stampings from titanium alloys has the chemical stability, which considerably exceeds the stability of base metal. Virtually it is not soluble in many aggressive media; therefore it is with difficulty removed by etching. Scale must be machined preliminarily in the fusion/melt of alkali or should be cleaned mechanically in the shot-blasting or hydroblast apparatuses, and then removed etching in the solutions/openings, indicated in the table. Technology of mechanical cleaning is the same as in remaining stampings. ENDFOOTNOTE.

(18). solution/opening. (19). Bronze Бр. АЖМ. (20). Brass. (21). Glossy carbon black. (22). Preliminary etching. (23). Glossy etch з.

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Basic Defects and Methods of their Elimination.

Together with the well-known defects/flaws, such, as incomplete filling, the misalignment, the loss of geometric dimensions, that occur and during stamping of structural steel, are encountered specific for the alloys of nonferrous metals defects/flaws defects/flaws (Tables 55-57).

55. The most widely used defects/flaws of the waste/reject of stampings from titanium alloys.

(1) Причины	(2) Методы устранения
(3) *Трещины по линии разъема*	
(4) 1. Некачественный металл. (5) 2. Металл плохо нагрет. (6) 3. Недостаточная толщина облоя. (7) 4. Мал радиус выхода из полости в облой. (8) 5. Штамповка на молоте завышенной мощности.	(9) При качественном металле и хорошем его нагреве перед штамповкой необходимо: (10) 1. Утолстить облой. (11) 2. Увеличить радиус выхода в облой. (12) 3. Штамповать на молоте нужной мощности.
(13) *Прострелы у оснований ребер*	
(14) 1. Чрезмерно тонкие ребра. (15) 2. Мал радиус сопряжения ребра с полотном. (16) 3. Плохо нагрет металл. (17) 4. Плохо прогрет штамп. (18) 5. *Слишком тонкое полотно.*	(19) При хорошем нагреве металла и достаточном прогреве штампа необходимо: (20) 1. Увеличить радиус сопряжения ребра с полотном. (21) 2. Утолстить ребро. (22) 3. Утолстить полотно.
(23) *Зажимы*	
(24) 1. Плохая укладка заготовки. (25) 2. Нехватка металла в месте образования зажима.	(26) 1. Точно укладывать исходную заготовку, перекрывая те места полости, где образуется зажим. (27) 2. Увеличить, или более правильно распределить объем металла в исходной заготовке.
(28) *Складки*	
(29) Неправильное течение металла от: (30) 1. Неправильной формы исходной заготовки. (31) 2. Неправильной кладки заготовки (32) 3 Нарушения режима нагрева	(33) 1. Заготовка должна перекрывать полость штампа, чем предотвращается перемещение металла вдоль полости
(34) *Разнозернистая структура в сечении поковки*	
(35) В утолщенных местах поковок и особенности из алюминиевых сплавов имеет место *крупнозернистая структура*, что является следствием многократных нагревов и небольших степеней деформаций	1. *Исходная заготовка должна быть выбрана* с учетом нужной деформации в утолщенных местах поковок (36)

Key: (1). Reasons. (2). Methods of elimination. (3). Cracks along parting line. (4). Poor quality metal. (5). Metal is badly/poorly heated. (6). Insufficient thickness of flash. (7). Radius of output from cavity in the flash is low. (8). Drop forging of high power. (9). During good-quality metal and its good heating before stamping it is necessary. (10). To thicken flash. (11). To increase radius of output in the flash. (12). To stamp on hammer of necessary power.

(13). Leakages in bases/roots of edges/fins. (14). Excessively thin edges/fins. (15). Radius of coupling edge/fin with hammer is low. (16). Metal is poorly heated. (17). Die/stamp is poorly thoroughly heated. (18). Too thin a fabric. (19). During good heating of metal and sufficient warming up of die/stamp it is necessary. (20). To increase radius of coupling edge/fin with fabric. (21). To thicken edge/fin. (22). To thicken fabric. (23). Clamps. (24). Poor setting blank. (25). Deficiency of metal in place of formation of clamp. (26). Accurately set the initial blank, overlapping those places for cavity, where clamp is formed. (27). To increase, or more correctly, to distribute volume of metal in initial blank. (28). Folds. (29). Incorrect metal flow from. (30). Irregular shape of initial blank (31). Incorrect laying of blank. (32). Disturbances/breakdowns of mode/conditions of heating. (33). Blank must overlap die cavity how is prevented displacement/movement of metal along cavity. (34). Heterogranular structure in section/cut of forging. (35). In thickened places of forgings in particular from aluminum alloys coarse-grained structure occurs, what is consequence of repeated heatings and small degrees of deformations. (36). Initial blank must be selected taking into account necessary deformation in thickened places of forgings.

56. Defects/flaws of forgings from titanium alloys, their reason and the methods of elimination.

(a) Причины	(b) Способы устранения
(c) *Трещины и надрывы*	
(1) а) Малая технологическая пластичность; (2) б) *Ковка при низких температурах;* (3) в) Местное подстуживание во время ковки	(4) *Легкие удары молота или ковка под прессом* ([illegible] ВТ1а); (5) Температура конца ковки не ниже оговоренной в таблицах; Подогрев инструмента не ниже [illegible]° С. (6)
(7) *Поверхностные трещины*	
(8) а) Образование глубокого хрупкого альфированного слоя в результате нагрева перед ковкой при температурах выше 1000° С и большое время нагрева при этом. (9) б) Грубообработанная или необработанная с дефектами поверхность заготовок.	(10) Нагрев производить при минимально возможных температурах, минимально возможное *время* или в защитной среде (аргон или гелий). Механическая обработка не ниже ▽4 или пологая зачистка дефектов наждачным камнем (11)
(12) *Внутренние трещины*	
(13) 1. Металлургические дефекты в слитках: *а*) Раскованшиеся включения W, Mo, Cr. б) Раскованшиеся включения накислороженных участков, как результат введения окисленных кусков отходов или как результат накислороженных кусочков губки. (14) 2 Затекание смазки при прессовании прутков.	(15) Отбраковывание заготовок путем рентгеновского просвечивания и ультразвукового контроля заготовок
(16) *Включения*	
(17) Металлургические дефекты в слитках W, Mo, Cr, *окисленные пленки, при добавлении при выплавке отходов включения по-иному травящихся* участков (полос или пятен) другого химического состава	(18) Отбраковывание заготовок путем рентгеновского просвечивания заготовок и ультразвукового контроля
(19) *Неравномерная и грубая структура, неравномерные и низкие механические свойства*	
(20) а) Недостаточная проработка металла. (21) б) Высокая температура ковки. (22) в) Разогрев металла во время ковки. г) Неравномерный прогрев металла. (23)	(24) Ковка методом 2—3-кратной осадки-протяжки со сменой граней и ребер с постепенным снижением температуры ковки с β-области до температуры ($\alpha + \beta$)-области. Окончательная ковка с температуры ($\alpha + \beta$)-области. (25) Ковка на менее мощном оборудовании более слабыми ударами молота или обжатиями пресса (26)

Key: (a). Reasons. (b). Methods of elimination. (c). Cracks and strains. (1). Low technological plasticity. (2). Forging at low temperatures. (3). Local cooling down during forging. (4). Taps of hammer or press forging (alloy BT15). (5). Temperature of end of forging not lower than stipulated in tables. (6). Preheating instrument is not lower than 250°C. (7). Surface cracks. (8). Formation of deep brittle alpha-deposited layer as a result of heating before ductile at temperatures of higher than 1000°C and long heating time in this case. (9). Coarse-machined or untreated with surface defects of blanks. (10). Heating to produce at smallest possible temperatures, smallest possible time or in protective medium (argon or helium). (11). Machining is not below ∇4 or slanting trimming of defects/flaws by emery stone. (12). Internal cracks. (13). Metallurgical defects/flaws in ingots: a) hammered out inclusions/connections W, Mo, Cr. b) the hammered out inclusions of the oxygenized sections as the result of the introduction of the oxidized pieces of withdrawals/departures or as the result of the oxygenized small pieces of sponge/jaw. (14). Flowing in of lubrication during extrusion/pressing of rods. (15). Rejection of blanks via fluoroscopy and ultrasonic test of blanks. (16). Inclusions/connections. (17). Metallurgical defects/flaws in ingots W, Mo, Cr, oxidized films, during addition with melting of withdrawals/departures of switching on of differently etched sections

(bands or spots) of another chemical composition. (18). Rejection of blanks via fluoroscopy of blanks and ultrasonic test. (19). Nonuniform and rough structure, nonuniform and low mechanical properties. (20). Insufficient study of metal. (21). High temperature of forging. (22). Heating of metal during forging. (23). Nonuniform warming up of metal. (24). Forging by method of 2-3-fold upsetting-drawing with replacement of faces and edges/fins with gradual reduction/descent in forging temperature from the β-region to temperature $(\alpha+\beta)$-region. (25). Final forging from temperature $(\alpha+\beta)$-region. (26). Forging on less powerful/thick equipment by weaker blows of hammer or by reduction of press.

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57. Defects of the forgings of copper alloys and the methods of their elimination.

(1) Причины	(2) Способы устранения
(3) *Скол под углом 45°*	
(4) Образуется при осадке малопластичных трудно деформируемых сплавов при применении больших деформаций	Уменьшить степень деформации при осадке (5)
(6) *Трещины на боковой поверхности осаживаемой заготовки*	
(7) Вызываются растягивающими напряжениями и деформациями на боковой поверхности вследствие увеличения диаметра осаживаемой заготовки в процессе осадки	Устранить неровности (концентраторы напряжений) на боковой поверхности и уменьшить степень деформации при осадке (8)
(9) *Расслоение*	
(10) Происходит вследствие высокой химической неоднородности (ликвации, пористости и других металлургических дефектов) в центральной части слитка или заготовки	(11) Увеличить степень деформации до величины, при которой во всех трех зонах осаживаемой заготовки она была более критической, более 15%
(12) *Неравномерная структура металла после осадки получается вследствие неравномерной деформации и образования зон в осаживаемой заготовке с различной деформацией*	

Key: (1). Reasons. (2). Methods of elimination. (3). Chipping at angle of 45°. (4). It is formed with the upsetting of slightly elastic difficultly malleable alloys during use/application of large deformations. (5). To decrease degree of deformation with upsetting. (6). Cracks on lateral surface of upset blank. (7). They are caused by tensile stresses and deformations on lateral surface as a result of increase of diameter of upset blank in process of upsetting. (8). To remove inequalities (stress concentrators) on lateral surface and

to decrease degree of deformation with upsetting. (9). Lamination. (10). It occurs as a result of high chemical heterogeneity (liquation, porosity and other metallurgical defects/flaws) in center section of ingot or blank. (11). To increase degree of deformation to value, with which in all three zones of upset blank it was more critical, is more than 15%. (12). Nonuniform structure of metal after upsetting is obtained as a result of nonuniform deformation and formation of zones in upset blank with different deformation.

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Chapter 6.

FORGING AND STAMPING OF BERYLLIUM AND ALLOYS.

Beryllium.

The chemical composition, physical and mechanical properties. Metallic beryllium is obtained by its thermal restoration/reductic from the fusion/melt of salts or electrolytically. Obtained by one of these methods beryllium is remelted in the vacuum ovens.

Technical melted beryllium has the following chemical composition:

(1) Be (по разности)	Fe	Mn	Si	Ni	Al	Mg	C
98,5—99,5	0,1—0,5	0,05—0,07	0,1—0,15	0,05	0,05—0,1	0,05	0,05—0,1

Key: (1). Be (on the difference).

The admixtures/impurities of such metals as Ag, Cr, B, Cd, Li,

etc., are contained in considerably smaller quantities. Oxygen, depending on the method of obtaining the metal, is contained in different quantities, mainly in the form of oxide of beryllium.

The metallic beryllium, obtained by remelting from the electrolytic scales, has less than admixtures/impurities to comparison with the beryllium, obtained by remelting from it is regulus the thermally restored/reduced metal.

Further cleaning admixtures/impurities from metal is produced via distillation, zone refining and other methods.

The cast beryllium, obtained by induction melting in the vacuum or electron-beam melting, can be used as the blank for the working by pressure. However, coarse grain of casting complicates the process of processing and it does not make it possible to obtain sufficiently high mechanical properties. The limit of the strength of casting does not exceed 15-20 kg/mm^2, but elongation per unit length is virtually close to zero. Cast beryllium possesses low technological plasticity during the working by pressure [69] and [84].

The low quality of cast material is to a considerable extent caused also by the tendency of the molten beryllium toward the gas saturation, which can cause the appearance of pores and cracks in the

crystallizing casting, and also by the extremely high chemical activity of this metal, which enters in the liquid state in the chemical interaction with the majority of elements/cells, including with the material of crucible.

However, if during the working by pressure it is possible to strongly grind grain of casting and to avoid the appearance of cracks and other seats of decomposition, then deformed - preliminarily pressed extrusion - metal is not inferior on the quality to the metal, obtained from the powder blank.

By the most promising ways of an improvement in the quality c cast beryllium for the purpose to make possible its use/application as the blank for the extrusion/pressing, forgings and stampings, should be considered alloying with its low additives Ti, Nb, Zr and other elements/cells, which grind the structure of melted metal, effect on the metal ultrasound, the centrifugal casting, crystallization under the pressure.

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Cermet blanks - basic form of materials on the basis of beryllium, which in practice found use for manufacturing of forgings and stampings. They are obtained by the hot pressing of powder in +he

vacuum or by preliminary extrusion from the hot-pressed material on the powerful/thick presses. Possibly also obtaining forgings and stampings of beryllium is direct from the powders by the method of hot pressing in the vacuum.

The type of initial metal, its purity/finish, method of the preparation of powder and value of the particles of the powder exert a substantial influence on the properties of blanks and deformed semi-finished products. Table 1 shows the purity/finish of the types of the beryllium, obtained by different methods. The standard powder of brand QMV of the common and increased purity/finish (firm Brush Beryllium Corp., USA) is manufactured from the distilled beryllium, obtained by the method of restoring the fluoride of beryllium by magnesium. At present the powder of brand QMV, and also the powder, obtained via electrolysis from the fusion/melt of beryllium chloride using the method of firm "Peshiney" (France) are the most widely used powders, produced in USA and France for the manufacture of articles made of the beryllium.

Compact blanks of the powder of beryllium abroad are obtained by hot pressing in the vacuum ovens at a residual pressure 10^{-2}-10^{-3} mm Hg and at 1100-1200°C in the graphite molds at the specific pressure 50-60 kg/mm² for several hours. Blanks acquire in this case the density, close to the theoretical (1.85). Is possible obtaining

compact blank by cold molding with subsequent sintering [84].

Table 2 gives the data about the effect of nature of powder (methods of obtaining the powder) on the mechanical properties of the bar blanks, extruded [1] at a temperature of 450°C with the degree of stretch of approximately 4:1 of the blanks, obtained by hot pressing at 1050°C and pressure 7 kgf/cm [84].

FOOTNOTE In contrast to the hot pressing of beryllium, product of which are compact blank, briquette, extrusion/pressing through the matrix/die is accepted to call extrusion, extrusion. ENDFOOTNOTE.

¶ Fig. 1 shows the effect of grain size to the mechanical properties of the beryllium hot-pressed in the vacuum depending on temperature. As can be seen from graph, finely dispersed powders provide, especially at temperatures to 600°C, higher characteristics.

1. The chemical composition of different types of the powder of beryllium [69, 84].

(1) Сорт бериллия	(2) Be в %	(3) Примеси в %						
		Fe	Ni	Al	Mg	C	O_2	Cl
(4) Стандартный порошок марки QMV (США)	99,0—99,0	0,15	0,05	0,03	0,05	0,07	0,6	—
(5) То же, повышенной чистоты	99,4—99,8	0,04	0,03	0,01	0,005	0,04		
(6) Порошок электролитический фирмы «Peshiney» (Франция)	99,8	0,000	0,008	0,06	0,001	0,06	0,00	0,0008
(7) Хлопьевидный электролитический (Франция)	99,4	0,039	0,0165	0,0095	—	0,05	0,29	0,29
(8) Многократно дистиллированный (A. W. R. E, США)	99,9	0,0035	0,012	0,008	0,0002	0,015	0,025	0,015
(9) Зоннорафинированный после 5 проходов	99,95	0,004	0,001	0,0001	0,002	0,018		0,0002

Key: (1). Type of beryllium. (2). Be in %. (3). Admixtures/impurities in %. (4). Standard powder of brand QMV (USA). (5). Highly purified, the same. (6). Powder electrolytic of firm "Peshiney" (France). (7). Flake-shaped electrolytic (France). (8). Repeatedly distilled (A. W. R. E, USA). (9). Zone-refined after 5 passes.

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This is caused by an increase in the specific surface area of grains with the decrease of their size, and also by an increase in the content of oxide of beryllium, since the oxidation of surface [84] occurs in the process of grinding, hot pressing.

Fig. 2 shows an increase in the content of BeO with an increase

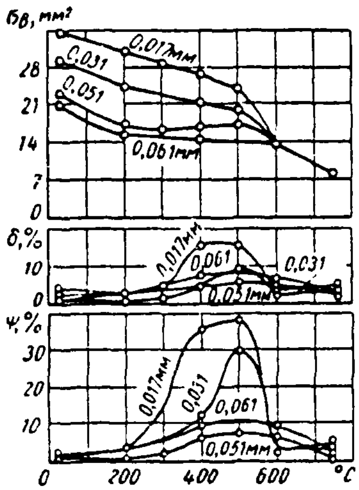
of the specific surface area of grains in the powder and respectively an increase in the limit of strength and elongation per unit length [84].

The accepted in the world practice standard powder - 200 mesh size (-56 μ) has maximum grain 70 μ, average particle size of approximately 20 μ and specific surface area of 1500-1900 cm^2/g [84].

2. Mechanical properties of the samples/specimens of beryllium, manufactured from different forms of powder [84].

(1) Свойства	(2) Порошок, полученный восстановлением из паровой фазы (5—12 мк)	(3) Порошок, полученный электролизом (420—840 мк)	(4) Порошок, полученный измельчением электролитических хлопьев (15—25 мк)	(5) Порошок, полученный измельчением отлитых в вакууме слитков (15—25 мк)
$\sigma_в$ в кГ/см² (6)	22,3	18,5	42,5	52,8—74,0
$\sigma_т$ в кГ/см² (6)	18,0	16,7	42,4	28,1—45,6
δ в % (7)	1,1	2,1	0,5	6—8
ψ в % (7)	0,8	1,5	0,3	

Key: (1). Properties. (2). Powder, obtained by restoration/reduction from vapor phase (5-12 μ). (3). Powder, obtained by electrolysis (420-840 μ). (4). Powder, obtained by grinding electrolytic flakes (15-25 μ). (5). Powder, obtained by grinding poured in vacuum ingots (15-25 μ). (6). in kgf/cm². (7). in %.



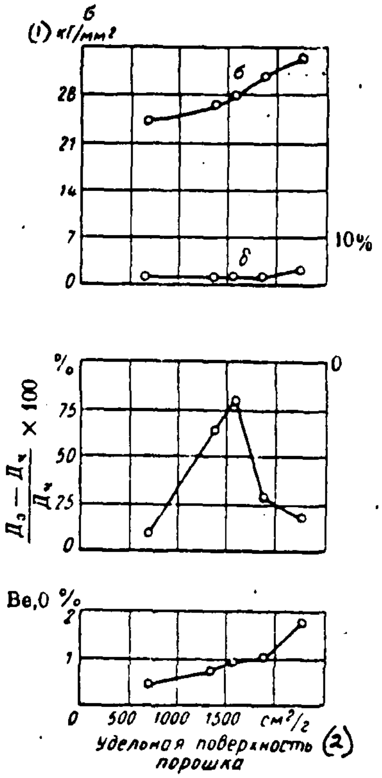


Fig. 1.

Fig. 2.

Fig. 1. Effect of grain size on mechanical properties at elevated temperatures of hot-pressed in vacuum beryllium QMV [84].

Fig. 2. Some properties of beryllium, hot-pressed in vacuum, depending on value of specific surface area of beryllium powder [62]; $Д_э$- diameter of grain after sintering; $Д_ч$- diameter of particle.

Key: (1). kg/mm^2. (2). Specific surface area of powder.

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The presence of oxygen (oxide film) has a positive effect on properties, since grain-growth with hot pressing (1100-1200°C) impedes. In the absence of oxide film (or with the low oxygen content) at these temperatures rapid grain-growth occurs.

A considerable effect on the mechanical properties of blanks have also the available in the beryllium admixtures/impurities, especially Fe, Al, Si and C [79].

The solubility of iron in the beryllium is small ~2.5% weight (0.9% at) at 1225°C. With a reduction/descent in the temperature the solubility sharply is decreased. Beryllium with the iron forms the series/row of the intermetallic compounds Be_2Fe, Be_5Fe, $Be_{11}Fe$, which even with the low content embrittle metal.

Especially harmful impurity is carbon, which, forming carbides, not only embrittles beryllium, but also is caused the intercrystalline corrosion of material.

Aluminum and silicon with those defined content (0.6-0.1%)

relationship/ratio (Al/Si=0.21) can beneficially affect during the sintering both the decrease of porosity and mechanical properties [79].

Table 3-5 gives the physical and mechanical properties of the beryllium at a room temperature, obtained by extrusion/pressing from the powder of brand QMV (USA).

The most valuable property of the hot-pressed beryllium is isotropy property in all directions. This is explained first of all by the fact that grains in the process of extrusion/pressing (in the closed container), which is characterized by the very high and uniform stresses/voltages of cubic compression, occupy the most varied position. High-pressure use/application with the specific forms of processing, for example extrusion, subsequently leads to the ordering of texture, the formation of texture and causes, as a rule, the considerable anisotropy of mechanical properties in the direction of the axis/axle of extrusion and in the perpendicular direction.

Therefore, from the point of view of the guarantee of the greatest uniformity of properties, the hot-pressed blank is best initial slug, stamping and others water-in the working by pressure.

The mechanical properties of the hot-pressed blanks are given in Fig. 3 and 4.

3. Physical properties of beryllium.

(1) Наименование показателей	(2) Показатель
(3) Плотность при 20° С в г/см³	1,85
(4) Температура плавления в °С	1283
(5) Температура кипения в °С	2970
(6) Удельная теплоемкость в кал/1° С при температуре в °С:	
20	0,46
100	0,51
200	0,56
300	0,58
400	0,63
500	0,65
600	0,69
700	0,71
800	0,74
(7) Коэффициент теплопроводности в кал/см·сек° С при температуре в °С:	
100	0,35
200	0,33
300	0,30
400	0,28
500	0,26
600	0,24
(8) Средний коэффициент линейного расширения в 10⁶·1/° С в интервале температур в °С:	
25—100	11,6
25—200	13,5
25—300	14,5
25—400	15,3
25—500	15,9
25—600	16,5
25—700	17,0
25—800	17,4
100—200	16,0
200—300	15,6
300—400	17,0
400—500	17,9
500—800	18,5
(9) Удельное электросопротивление при 25° С в мком·см	3,84
(10) Скорость распространения звука в м/сек	12600
(11) Отражательная способность (для белого цвета)	50—55
(12) Поперечное сечение захвата тепловых нейтронов в барн/атом	0,0090 (±0,0005)

Key: (1). Designation of indices. (2). Index. (3). Density with 20°C V g/cm³. (4). Melting point in °C. (5). Boiling point in °C. (6). Specific heat in cal/1°C at temperature in °C. (7). Coefficient of thermal conductivity in cal/cm·s °C at temperature in °C. (8). Average coefficient of linear expansion in 10⁶·1/°C in range of temperatures in °C. (9). Specific resistance with 25°C V μΩ·cm. (10).

Sound propagation velocity in m/s. (11). Reflectivity (for white color). (12). Cross section of capture/grip of thermal neutrons in b/atom.

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Giving a comparative evaluation of the pressed and extruded blanks (against latter/last for greater detail, see below) it should be pointed out that the absence of the anisotropy of properties gives the possibility to deform the hot-pressed blank in any direction, whereas preliminarily textured material (rod, band) when the large anisotropy of properties is present, requires special approach dur j the selection of method and direction of strain. However, properties, especially ultimate strength and the elongation per unit length of the textured material in the direction of the drawing of grain, 2-3 times often exceed the properties of the hot-pressed blanks. Therefore during the selection of slug and stamping the part, which in the construction/design in the determinate directions bears large loads, should be utilized the textured material, obtained by the method of extrusion (extrusion/pressing through the matrix/die).

4. Mechanical properties of pressed by different methods beryllium [62, 84].

(1) Характеристика металла	(2) Механические свойства	
	(3) $\sigma_в$ в $кГ/мм^2$	(4) δ в %
(5) Холоднопрессованный и спеченный при 1050° С	22,5	0,1
(6) Теплопрессованный:		
(7) при 450° С и давлении 14 $Т/см^2$	21,2	0,2
(8) при 565° С и давлении 9,85 $Т/см^2$	32,3	0,1
(9) при 650° С и давлении 7,0 $Т/см^2$	40,9	
(10) Теплопрессованный при 450° С и давлении 14 $Т/см^2$ и спеченный в вакууме при 1050° С	25,2	
(11) Горячепрессованный:		
(12) при 750° С и давлении 2,1 $Т/см^2$	38,5	0,0
(13) при 1100° С и давлении 0,2 $Т/см^2$	47,8	1,4

Key: (1). Characteristic of metal. (2). Mechanical properties. (3). in kg/mm². (4). δ in %. (5). Cold-pressed and sintered at 1050°C. (6). Heat-pressed. (7). at 450°C and pressure 14 t/cm². (8). at 565°C and pressure 9.85 t/cm². (9). at 650°C and pressure 7.0 t/cm². (10). Heat-pressed at 450°C and pressure 14 t/cm² and sintered in vacuum with 1050°C. (11). Hot-pressed. (12). at 750°C and pressure 2.1 t/cm². (13). at 1100°C and pressure 0.2 t/cm².

5. Mechanical properties of beryllium from powder QMV (USA) [62, 84] hot-pressed in the vacuum.

(1) Наименование показателей	(2) Показатели
(3) $\sigma_в$ в кГ/мм²	31,9
(4) $\sigma_т$ при растяжении в кГ/мм²	22,6
(5) δ в %	2,3
(6) E при растяжении в кГ/мм²	31,3·10³
(7) α в кГ/мм²·град	−5,3
(8) $\sigma_т$ при сжатии (0,2%) в кГ/мм²	17,2
(9) E при сжатии в кГ/мм²	31·10³
(10) Коэффициент Пуассона	0,024
(11) G при кручении в кГ/мм²	27,5
(12) G при двойном срезе в кГ/мм²	25,5
(13) $a_н$ (образцы без надреза) в кГм/см²	0,11
(14) Работа ударного разрушения при растяжении в кГм	1,19

Key: (1). Designation of indices. (2). Indices. (3). in kg/mm². (4 with elongation in kg/mm². (5). δ in %. (6). E with elongation in kg/mm². (7). α in kg/mm²·deg. (8). during compression (0.2%) in kg/mm². (9). E during compression in kg/mm². (10). Poisson ratio. (11). G during torsion in kg/mm². (12). G during dual shear/section in kg/mm². (13). (samples/specimens without cut) in kgfm/cm². (14). Work of percussive tensile failure in kgfm.

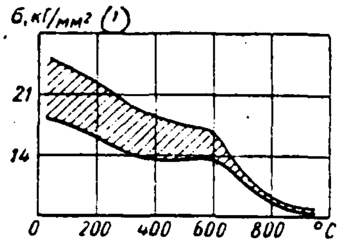

Fig. 3.

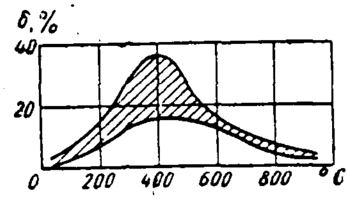

Fig. 4.

Fig. 3. Boundaries/interfaces of values of limit of strength of hot-pressed beryllium of brand QMV depending on temperature [62, 84].

Key: (1). kg/mm².

Fig. 4. Boundaries/interfaces of values of elongation of hot-pressed beryllium of brand QMV depending on temperature [62, 84].

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Thus, the increased strength of the textured material in the direction of extrusion can be effective used in the construction/design. When the considerable anisotropy of the properties of material is not allowed/assumed on construction/design conditions, one should produce the forging (upsetting) of the extruded blank for the purpose of deformation in the perpendicular

direction to the axis/axle of extrusion, or utilize the hot-pressed blanks. However, the latter on the strength in one of the directions will somewhat be inferior to the blank, obtained by the first method.

Technological processes. Extrusion/pressing by extrusion is considered as the method of the preliminary strain of ingots or cermet blanks before the ductile and the stamping.

Beryllium has the hexagonal close-packed lattice with parameters a_0=2.2854 Å, c_0=3.5829 Å, c_0/a_0=1.5677.

The strain of beryllium occurs in essence due to the shift/sh on the plane of base (0001) and prism $\{10\bar{1}0\}$, moreover in both cases in direction $[12\bar{1}0]$. Twinning occurs on planes $[10\bar{1}2]$ in direction $[10\bar{1}\bar{1}]$, and decomposition on basal planes (0001) and prism $\{1\bar{2}10\}$. With the elongation insignificant shift/shear on the plane of base (elongation 2-3%) is observed, after which the fracture begins. During the compression the shift/shear on the plane of base is feasible more considerable. Under the conditions, when elongation is basic stress/voltage or when considerable elongation in one direction occurs, is observed the reorientation of crystals in such a way that basal planes (0001) are furnished in parallel to the direction of axis of dilatation.

Fig. 5 shows the dependence of the breaking stresses of shift/shear basal planes and prism from temperature [83]. As can be seen from the figure of up to 500°C of the stresses/voltages, necessary for the shift/shear on the plane of prism considerably higher than breaking stresses on the plane of base, and at a temperature of ~500°C they become approximately/exemplarily equal.

With the extrusion, as during the rolling, as a result of strain occurs the considerable development of texture, basal planes obtaining preferred orientation, as has already been discussed this, in parallel to the direction of elongation. The degree of the orientation of basal planes is found in direct dependence on the degree of strain (Fig. 6). Upon reaching/achievement of drawing more than 15:1 or 20:1 further strengthening of orientation virtually is not observed [69, 84], which will agree well with the results of mechanical tests.

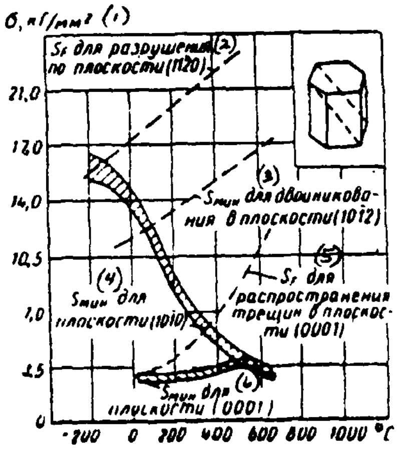

Fig. 5. Dependence of the breaking stresses of shift/shear on basal planes and prism from temperature [69, 83, 84].

Key: (1). kg/mm². (2). for decomposition on the plane (11$\bar{2}$0). (3). for twinning in plane (10$\bar{1}$2). (4). for plane (10$\bar{1}$0). (5). for crack propagation in plane (0001). (6). for plane (0001).

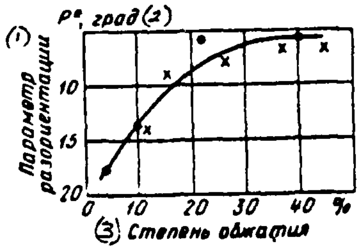

Fig. 6. Effect of extrusion ratio and rolling on ordering of arrangement of basal plane [69].

Key: (1). Parameter of disorientation. (2). deg. (3). Degree of reduction.

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During the drawing of more than 15:1 elongation remains constant. On the level of the mechanical properties of material heat treatment has a great effect.

Warmer extrusion [64, 69] with an increase in the drawing to 6.25:1 leads to an increase in the limit of strength and viscosity/yield: first rapid (to 2:1), and then retarding. However, elongation slowly grows/rises to 11% during drawing 2.25:1, and then it begins to decrease to 5% during drawing 6.25:1.

With hot extrusion [64, 69] at 1070°C increase in the drawing from 12:1 to 38:1 led to an insignificant increase in the tensile strength. Elongation grew/rose with 13% during drawing 12:1 to 19% during drawing 15:1 and with the large reduction an increase in the elongation ceased, in connection with the delay/retarding/deceleration of the development of texture with the large reduction (see Fig. 6).

A reduction/descent in the temperature of hot pressing from 1100

to 900°C (with reduction 20:1) was accompanied by an increase in the limit of strength and yield point [65, 69].

On the mechanical properties of the deformed beryllium besides degree and character of strain have an effect the size of the grain of initial powder, heat treatment, quality of surface, including technology of the surface treatment by cutting [65, 69].

The temperature of extrusion has fundamental importance. With by heat extrusion (400-500°C) the material is plastic and possesses a sufficient safety factor. However, extrusion at these temperatures requires large efforts/forces; therefore by warm extrusion virtual it is not possible to obtain bar blank by the drawing of more than 5-6:1. Strain occurs mainly due to the slip on the plane of base 0001, grain is lengthened, some grains are ground [65, 69].

With the hot extrusion (above 800°C) the strain passes also due to the fragmentation of grain, since grain at high temperatures loses safety factor, slip occurs both on the plane of base and on the plane of prism, since breaking stresses for the slip along both planes at high temperatures are aligned.

Fig. 7 [84, 73, 69] gives the diagram of the recrystallization of cast beryllium. The recrystallization of the deformed cermet

beryllium at a temperature to 780°C is restrained by the presence of oxide film on the surface of each grain. Annealing at a temperature of >1000°C leads to extremely rapid grain-growth. The decrease of grain size and, therefore, an increase in the content of oxide of beryllium (see Fig. 2) also somewhat restrains the process of recrystallization.

Annealing at a temperature of >800°C causes also the seal of defects/flaws, especially surface cracks, obtained as a result of machining. At a temperature of >800°C the diffusion splicing (welding) of beryllium occurs. Heat treatment decreases the internal stresses/voltages, which arose both as a result of strain and as a result of the subsequent machining.

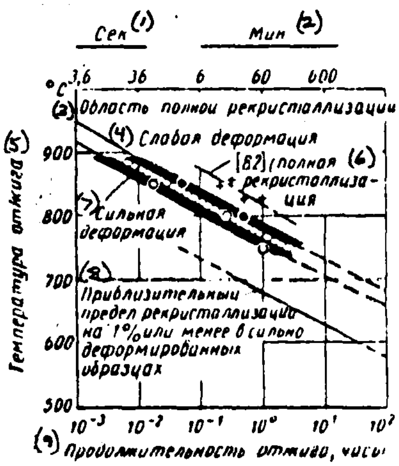

Fig. 7. Diagram of the recrystallization of cast beryllium [73, 84, 69].

Key: (1). s. (2). min. (3). Region of complete recrystallization. (4). Weak strain. (5). Temperature of annealing. (6). [82] (complete recrystallization. (7). Severe strain. (8). Approximate limit of recrystallization to 1% or is less in strongly deformed samples/specimens. (9). Annealing time, hours.

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Fig. 8 shows the temperature effect of tests for mechanical properties of beryllium [73, 69]. Should be noted a sharp decrease in the plasticity at a temperature about 600°C. In the bar blanks with the high degree of strain, and also in the hot-pressed blanks the

incidence/drop in the plasticity in this region can be even sharper. Higher than 600°C plasticity somewhat increases. Temperature range of 600°C is characterized by junction from the transcrystalline fracture to the intercrystalline. At 600°C boundaries of grains are weakened/attenuated by the available admixtures/impurities, which with the annealing are dissolved in the matrix/die of grain increasing the plasticity of material with 600°C. Hence it follows that the strain of beryllium should be carried out at temperatures, where it possesses the maximum of plasticity. For the small degrees of strain this is the area of temperatures of 450-500°C, it is above for the high degrees of strain of 750°C.

The strain of beryllium, as a rule, carries out in the technological shells. The best material for the shells is low-carbon steel of brand St. 20, in some technological properties closest at temperatures of extrusion/pressing to the beryllium. Fig. 9 [76] shows the temperature effect to the constant of extrusion K for the beryllium in the comparison with copper and low-carbon steel. The constant of extrusion K enters into equation for calculating the effort/force of extrusion/pressing (extrusion)

$$p = K \ln R,$$

where p - specific pressure on the blank; R - reduction. As the shells for the strain with by heat extrusion/pressing it is possible to apply also copper.

Shell during the strain of beryllium plays very large role. First of all, it protects metal from the oxidation during the heating and eliminates entry/incidence into the surrounding space the aerosols of beryllium.

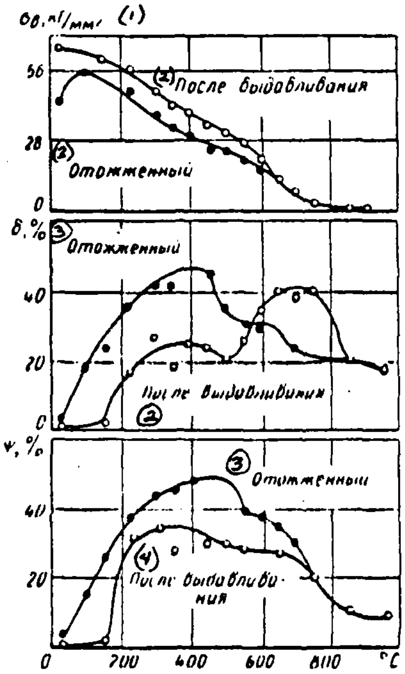

Fig. 8.

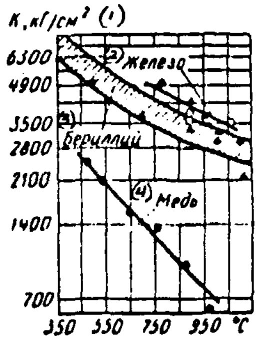

Fig. 9.

Fig. 8. Temperature effect of tests for mechanical properties of beryllium. Annealing was conducted at 750°C for 2 h.

Key: (1). kg/mm². (2). After extrusion. (3). Annealed. (4). After extrusion.

Fig. 9. Temperature effect on constant of extrusion K for beryllium in comparison with copper and low-carbon steel.

Key: (1). kgf/cm^2. (2). Iron. (3). Beryllium. (4). Copper.

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In the second place, due to the high reactions, created by the walls of massive shell, it provides the more favorable for the beryllium diagram of the stressed state - uniform compression.

One should consider that during the strain in the shells the material of shell at high temperatures can interact with the beryllium, being welded and forming brittle compounds - the intermetallic compounds of beryllium. Therefore strain temperature must not exceed 1000°C.

The strain of beryllium without the shells on the conditions of safety engineering can be produced only in the specialized locations.

As the technological lubricant with the hot extrusion are applied the mixture of oil of the type Vapor-T with graphite, or the glass lubricant, which gives the best results. With the extrusion of blanks without the shells they cover/coat their surface with several layers of colloidal graphite or with its mixture with molybdenum disulfide, which removes intense adhesion characteristic for the beryllium to the press tool.

For the extrusion the instrument made of high-speed steel (18% W, 4% Cr and 1% V), which allows/assumes specific pressure 1400 kgf/cm² is applied during the heating to 480-540°C.

Matrices/dies have approach cone with the angle in apex/vertex of 90°C, which facilitates decompression, which smoothly converts into the extended forming band, which removes the formation of the cross cracks, caused by elastic stresses.

Are applied the sectional dies, which are preferable with the extrusion on the upper limit of the temperature interval, when cone decreases cooling unit, insulating it from the less heated cylindrical matrix/die and thus is decreased the pressure of extrusion.

Forging and stamping. The processes of extrusion from the hot-pressed units of bars and profiles/airfoils are the most studied processes of the strain of beryllium. However, the technological processes of forging and stamping the beryllium are successfully applied for obtaining the articles and by the use of actual data, obtained with the hot pressing and the extrusion, since in the physical essence of these processes there is much in common.

Stamping parts from powder [67, 84]. Are possible the following three versions of obtaining stampings directly from the powder, the based on technology of obtaining compact cermet blanks - the units:

cold pressing with the subsequent sintering in the vacuum or the neutral medium;

hot die forging in the vacuum with the holding under the pressure;

stamping powder in the shells.

Lower half of die/stamp for cold pressing is performed in the form of container from the calculation, that the bulk weight of the powder of beryllium is 0.8-1 g/cm³. Powder can be consolidated by vibration or pre-pressing to 1.2 g/cm³. Extrusion/pressing is produced before reaching/achievement of a maximally possible density. The density of stampings is one of the main factors, which determine their mechanical properties (Fig. 10, 11, 12).

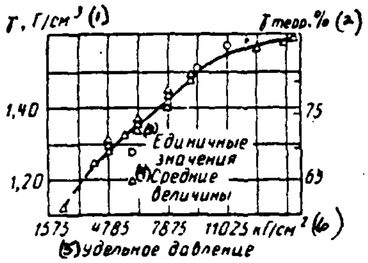

Fig. 10. Change of the density of stampings in the dependence on the specific compacting pressure [67, 84].

Key: (1). G/cm³. (2). theory, %. (3). Unit values. (4). Average values. (5). Specific pressure. (6). kgf/cm².

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Is most widely used the method of the hot die forging, with which is possible reaching/achievement of the density, close to the theoretical. The hot die forging of parts from the powder of beryllium is produced in the same furnaces of the hot pressing, which are commonly used for obtaining from the powder of compact cermet blanks. Matrix/die with the powder is set in the heater, located in vacuum chamber, assembled on the press. They evacuate air to the residual pressure 10^{-2}-10^{-3} mm Hg. Then they heat and stamp after reaching/achievement of the prescribed/assigned temperature. The pressure indicated they maintain during the time, necessary for

obtaining of the density, close to the theoretical.

In Fig. 13 are shown strength to fracture $\sigma_{изг}$ and density γ of the briquettes, pressed in 15 min in the vacuum under the pressure 3.9% T/cm^2 depending on the temperature of extrusion/pressing. One should from mark that the density close to the theoretical at this pressure and temperature of 600°C is reached after 1 min. An increase in the temperature makes it possible to considerably lower specific compacting pressure. At 1050-1150°C optimum pressure is 30-50 kgf/cm^2. The holding time depends on the height/altitude of article and it are selected experimentally. Main criterion of the quality of stamping - reaching/achievement of theoretical density [82, 84].

Stamping parts from beryllium powder according to the safety regulations can be produced only in the specially equipped locations.

With the work on the equipment, established/installed in the overall locations, the powder must be found in the sealed (welded) shell - container. The filling of powder into the container, its preliminary sealing/packing/compaction and seal of container must be produced in specially fitted out for this location. Material of container - low-carbon steel. With the seal from the container air is removed. Stamping temperature by 975-1000°C. After stamping the shell is removed by machining or they remove/release in hot 50% nitric acid.

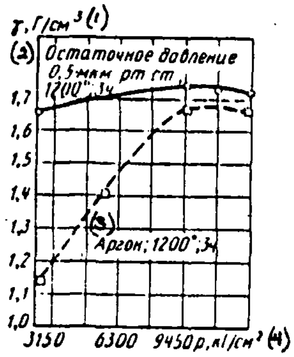

Fig. 11.

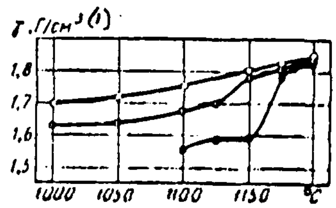

Fig. 12.

Fig. 11. Change of density of stampings in dependence on compacting pressure p and atmosphere of sintering [67, 84].

Key: (1). G/cm³. (2). Residual pressure 0.5 μm Hg; 1200°C; 3h. (3). Argon; 1200°C; 3h. (4). kgf/cm².

Fig. 12. Temperature effect of sintering on density of briquettes, pressed under pressure 12 T/cm² and which were being sintered for 5 h [84]: O - powder QMV; ◑ - powder, obtained from lamellated metal and machined by oxalic acid; ● - powder from ingot, smelted from lamellated metal.

Key: (1). G/cm³.

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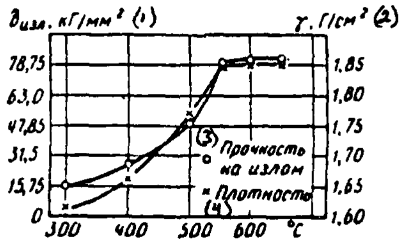

Fig. 13. Strength and the density of the briquettes, pressed in 15 min in the vacuum under the pressure 3.9 t/cm² depending on temperature [82, 84].

Key: (1). kg/mm². (2). G/cm². (3). Breaking strength. (4). Density.

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The surface layer, contaminated by iron, is etched at the depth of 0.025-0.05 mm in 5-% sulfuric acid. During stamping of powder in t container it is necessary to give considerable machining allowances, since virtually it is not possible to consider all factors, which determine the geometry of the obtained stampings.

Forging and stamping compact blanks. Like extrusion forging and stamping the blanks of beryllium produce both the hot at 900-1100°C and warm at 400-500°C both in the dies/stamps and with settling on the platens. Forging and stamping beryllium blanks they conduct on the standard forging-and-pressing equipment. With the work on the presses, established/installed in the overall locations, shells of low-carbon steel are applied. Blank is placed in the shell, is capped

from both sides and is welded by hermetically sealed weld. Use/application of the seamless or stamped/die-forged shells in the form of sleeves/beakers gives the best results. In this case they weld shell only on one side. During stamping of beryllium is applied the same technological lubrication as with the extrusion.

During the forging (settling) on the platens the wall thickness of shell must be selected taking into account the fact that in the places for intense strain the shell has a tendency toward thinning [68].

Fig. 14 and 15 show the diagrams of the processes of obtaining stampings of more complex configuration with the use of spring dies/stamps and dies/stamps with the clampings/tightenings, which limit stamping in tension areas [68].

Stamping without the shells can be produced only in the specialized location. During the stamping without the shell side elongation must not exceed 15%. Stamping temperature can be lowered/reduced to 400-500°C. Beryllium in this temperature range has sufficiently high strength and maximum elongation (see Fig. 3).

The temperature of heating blanks about 425°C provides a sufficient plasticity of beryllium for the filling of the complicated

figure of die/stamp.

Forging and stamping the preliminarily extruded blanks in comparison with stamping of the hot-pressed blanks has that special feature/peculiarity, that in the first case the material of blank due to the texture has mechanical properties along the axis/axle of extrusion 2-2.5 times higher than in the hot-pressed blanks. The properties of the preliminarily extruded blank across the axis/axle of extrusion (defined mainly by the properties of initial material) are the same as in the hot-pressed blank. During the stamping the anisotropy of the properties of material in comparison with the initial blank can be to a certain degree lowered/reduced depending the pattern of the flow of metal, determined by the configuration of stamping.

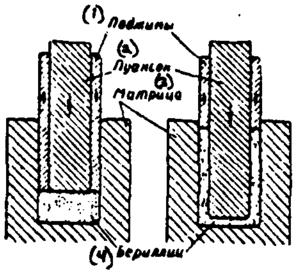

Fig. 14.

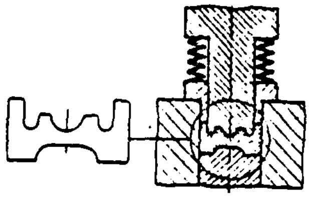

Fig. 15.

Fig. 14. Diagram of process of obtaining stampings with use of spring dies/stamps [66].

Fig. 15. Diagram of process of obtaining stampings with clampings/tightenings, which limit stamping in tension areas [66].

Key: (1). Clampings/tightenings. (2). Die. (3) Punch. (4). Beryllium.

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The properties of stamping of the hot-pressed blank depending on the type of stamping and direction can be 1.5-2 times of higher than the properties of blank.

Machining by the cutting of stampings from the beryllium. During stamping of beryllium in the shells they occur and the insufficiently

high surface finish, in connection with which after the removal/taking of shells the necessary final procedure is the machining of stampings. On the machinability the beryllium can be compared with such materials as gray cast iron (brand SCh 28-48), which has the allowable speed of cutting during the turning 190 m/min; however, the maximum speed of processing beryllium must be to 20-30% below.

The method of manufacturing the beryllium and the size of grain of the initial powder of blanks can exert certain effect on the machinability of beryllium by cutting and quality of surface after processing. The best results are obtained on the finely dispersed beryllium.

For the turning with the greatest effectiveness utilize the cutters with the cutting edge from the sintered hard alloys of the type BK6, BK8. Angle of tool sharpening of 20-40°. High value has the correct relationship/ratio of cutting speeds, the rate of the feed of cutter and depth of cutting. An increase in the cutting speed (in the limits of that permitted) and the decrease of the rate of the feed of cutter to 0.1 mm/rev must contribute to obtaining less rough surface.

The processes of milling the beryllium in their laws are analogous to turning. It is desirable to work beryllium without the

cooling fluid, in order to preserve for the secondary use to spokeshave.

All operations of working beryllium by cutting should be carried out in the special locations with the guarantee on the machine tools of strong local suction in the zone of cutter or special shelters and highly efficient general exchange/total exchange ventilation.

Grinding, polishing and the metallographic control of blanks and stampings of the beryllium. The brittleness of beryllium and the possibility of the emergence of cracks in the blanks and the stampings in the process of their working by pressure, the possibility of the appearance of the inclusions and heterogeneities in the structure of material attach important value to the metallographic control (macro- and microstructure) of blanks and stampings.

The macro-control/macro-check of blanks is carried out usually by the piece, and stampings - it is selective. In certain cases the grinding and the polishing are produced for the purpose of obtaining the high-quality surface of stampings.

The preparation of the sections of beryllium presents the definite difficulties, connected with the breaking-off of solid

structural components and the abrasion of section.

Preliminary grinding. Grinding must be carried out with a change in the direction on 90° on each wheel/circle. Wet grinding is recommended, but on the latter/last wheel/circle it is better to produce dry grinding.

Polishing can be produced with one of the following methods: common mechanical polishing; mechanical polishing with the etching; electrolytic polishing.

Common mechanical polishing is produced on a comparatively ri d cloth; as the abrasive in this case serves oxide of aluminum (crocus, carbide of silicon or diamond paste).

Mechanical polishing with the etching is produced on the same cloth, but fine-grained oxide of aluminum, weighed in 5-10%- aqueous solution of oxalic acid, is utilized as the abrasive.

For the electrolytic polishing is been commonly used the following composition of solution/opening: 900 ml H_3PO_4, 240 g CrO_3, 200 ml H_2O. Sample/specimen is worked on the anode during 1 min at a temperature of solution/opening of 70-80°C and current density 250 A/cm². As inert cathode they serve lead, stainless steel or graphite.

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More extensively is used the solution/opening of the following composition: 100 mm H_3PO_4 30 ml H_2SO_4 30 ml of glycerin, 30 ml of the absoluted ethyl alcohol. Processing sample/specimen is performed on the anode at a room temperature and the current density 2-4 A/cm²

with the use/application of an inert cathode.

The microexamination of section in the polarized light after polishing can be in certain cases produced without the etching.

For the investigations in the reflected light the sections preliminarily etch in 2-10%—solution of the concentrated hydrofluoric acid in the water, alcohol or glycerin. Etching by insertion/immersion on 1-3 min into the boiling 20% solution of oxalic acid also gives satisfactory results. The etching by 2% solution of nitric acid is applied for the bright dipping of grinding face.

Testing the microstructure of stampings. With the survey of section in the polarized light are revealed/detected the character of the structure of material, grain size and degree of its orientation,

the presence of structural heterogeneities, metallic and nonmetallic inclusions.

ALUMINUM-BERYLLIUM ALLOYS.

The chemical composition and mechanical properties. Alloys on the basis of system Al-Be (Table 6) are of great interest as structural material, since already with the content of beryllium it is more than 15-20%, to a considerable extent combine in themselves the very valuable properties of beryllium with the high plasticity of aluminum, which makes them in a technological respect with more convenient in comparison with the pure beryllium.

Beryllium-aluminum alloys are intended for the use/application in the constructions/designs of the rockets and other flight vehicles, especially for the elements of the constructions/designs, determining factor of which is rigidity.

By firm "Lockheed" (USA) are developed and are advertised dual high-modulus beryllium-aluminum alloys (without the additions of the alloying elements) of the type "lockalloy" (Table 7) for the use/application in space vehicles [70, 78, 80].

6. The chemical composition and the mechanical properties of aluminum-beryllium alloys with the additions of other elements/cells.

(1) Группа сплавов	(2) Химический состав	E	$\sigma_в$	(4) δ в %
		(3) в кГ/мм²		
(5) Не упрочняемые термической обработкой	(6) 15—60% бериллия и сумма других добавок до 15%	10 000—18 000	40—60	8—20
(7) Упрочняемые термической обработкой	(8) 15—40% бериллия и сумма других добавок до 10%	11 500—14 500	52—69	8—12

Key: (1). Group of alloys. (2). Chemical composition. (3). in kg/mm². (4). δ in %. (5). Not strengthened by heat treatment. (6). 15-60% of beryllium and sum of other additives to 15%. (7). Strengthened by heat treatment. (8). 15-40% of beryllium and sum of other additives to 10%.

7. Chemical composition and mechanical properties of pressed semi-finished products from dual beryllium-aluminum alloys "lockalloy" [71, 72, 77].

(1) Сплав	(2) Плотность γ в г/см³	E	$\sigma_в$	(4) δ в %
		(3) в кГ/мм²		
Be — 24% Al	1.99	26 000	—	—
Be — 33% Al	2.05	23 900	57.8	4
Be — 36% Al	2.08	22 500	53.4	1.2
Be — 43% Al	2,13	20 400	48.5	1,5

Key: (1). Alloy. (2). Density γ in g/cm³. (3). in kg/mm². (3). δ in %.

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Aluminum-beryllium alloys can undergo any forms of working by pressure, including to forging and stamping. However, in the cast state working it is expedient to begin from the extrusion/pressing with extrusion - method, which is characterized by the high values of the stresses/voltages of cubic compression.

As can be seen from the constitution diagram of system Al-Be (Fig. 16), of entire the being practical interest aluminum-beryll. .ı alloys are hypereutectic, in spite of this they possess a sufficient plasticity, that it is possible to explain by the presence in their structure of plastic aluminum matrix/die. Alloys have a heterogeneous structure, which consists of the primary beryllium phase (solid solution of aluminum in the beryllium) and the eutectic, which consists virtually of purity/finish aluminum [60, 71]. At present there are data about the presence of peritectic transformation in system Al-Be [88]. However, in comparison with the plastic standard aluminum alloys their plasticity somewhat below, which is connected with heterogeneity of structure and sharp difference in the properties of independent phases.

From a whole series of the developed alloys, not strengthened by heat treatment, most favorable combination of mechanical and technological properties possess the alloys of system Al-Be, which contain 20-30% of beryllium, with a density of γ=2.3-2.4 g/cm^3, the modulus of elasticity of which E=11000-14000 kg/mm^2 [85, 86, 87].

Methods of obtaining slugs and stamping [85, 86, 87]. Melting and casting with the subsequent working by pressure (upsetting, extrusion/pressing by extrusion). Melting is accomplished/realized in the induction vacuum furnaces in the medium of inert gas. The process of the melting of ingots is complex in view of wide solidification range and high chemical activity of beryllium in the molten state. Temperature of melting and casting 1140-1280°C. Graphite, corundum crucibles or crucibles from oxide of beryllium are applied for the melting. Ingot they differ into the massive graphite or copper ingot mold with weight not less than 10-20 times exceeding the weight of ingot. Casting into the water-cooled ingot mold is possible. Ingots have the following properties: the limit of strength σ_b = 25-32 kg/mm^2, δ to 10%. Fig. 17 shows the macrostructure of ingot, while in Fig. 18 its microstructure.

Cermet method consists of the following stages: casting ingot,

shaving formation (transformation into the shaving), grinding, hot pressing of powders in the vacuum or cold molding with the subsequent sintering in the vacuum.

Working by pressure of the alloys of system aluminum-beryllium, that have heterogeneous structure with the phases, which sharply differ in the plasticity, is accompanied by nonuniform deformation and emergence of tensile stresses, which with the adverse forms of working can lead to the decomposition of material.

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However, during the working by pressure the fundamental value has that the fact that aluminum component begins plastically to be deformed with the stresses lower than that stress, with which, occurs the strain of beryllium phase. The beryllium phase, distributed in the plastic aluminum matrix/die relatively evenly, flows together with it, by which is explained the fact that the aluminum-beryllium alloys under the conditions for cubic compression have a plasticity, which considerably exceeds the plasticity of pure beryllium. At the same time with the adverse forms of working with the high values of tensile stresses even before these stresses/voltages will achieve the value, necessary for the plastic deformation (or brittle decomposition) of beryllium phase, already begins plastically to be

deformed aluminum component of alloy, that also leads to the formation of cracks on the plastic, but less strong phase and the decomposition of articles.

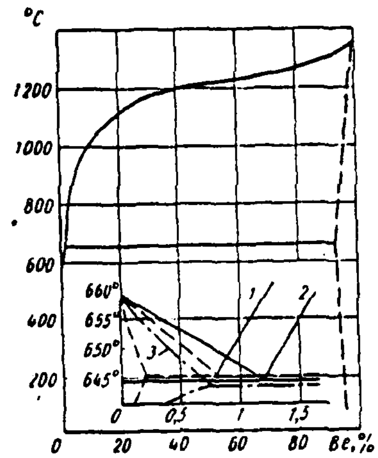

Fig. 16. Constitution diagram of systems Al-Be after data of: 1- Archer and Dinka; 2- Osterkel'd; 3- Khaaz and Uno.

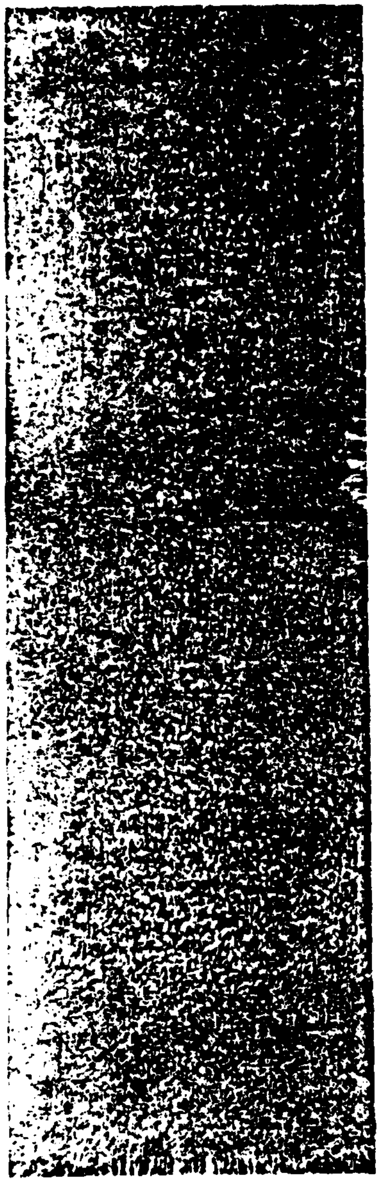

Fig. 17.

Fig. 18.

Fig. 17. Macrostructure of ingot of alloy, which contains 30% of

beryllium Ø127 mm.

Fig. 18. Microstructure of ingot of aluminum-beryllium alloy Ø127 mm.

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Thus, working by pressure of the alloys of system aluminum - beryllium, especially in the cast state should be conducted by the methods, which are characterized by the diagram of the stressed state of cubic compression, with high main compressive and minimum tensile stresses. The alloy, deformed under such conditions of the cast state subsequently preliminarily allows/assumes the more rigorous conditions for deformation, including during the forging and stamping.

The extrusion/pressing blanks by extrusion is preliminary ethane of working cast aluminum-beryllium alloys (Table 8).

Fig. 10 shows the construction/design of matrix/die for the extrusion/pressing by the extrusion of aluminum-beryllium alloys with the wide working band and the conical input/introduction to it.

In view of the lowered/reduced technological plasticity of alloys in comparison with the aluminum alloys working by pressure

must be produced them in the narrow temperature range. Table 9 gives comparative mechanical properties of the pressed blanks and sheet of the aluminum-beryllium alloy, which contains 30% of beryllium.

8. Modes/conditions of extrusion/pressing by the extrusion of aluminum-beryllium alloys [85, 86].

Матрицы (1)	Смазка контейнера (2)	Температура контейнера в °C (3)	Смазка слитка (4)	Температура слитка в °C (5)	Время выдержки слитка в печи в ч (6)	Скорость истечения металла в м/мин (7)	Удельное давление на прессшайбе в кГ/мм² (8)
Специальной конструкции (широкий рабочий поясок и конусный ввод к нему) (9)	Графит (25%) + масло Вапор Т (75%) (10)	280—330	Коллоидно-графитовая марки ОЛПВ (11)	380—420	2	6—12	25—60

Key: (1). Matrices/dies. (2). Lubrication of container. (3). Temperature of container in °C. (4). Lubrication of ingot. (5). Temperature of ingot in °C. (6). Time of holding of ingot in furnace in h. (7). Discharge velocity of metal in m/min. (8). Specific pressure on dummy block in kg/mm². (9). Special construction/design (wide working band and conical input/introduction to it). (10). Graphite (25%)+oil Vapor T (75%). (11). Colloidal graphite brand/mark.

9. Mechanical properties of semi-finished products from aluminum-beryllium alloys.

Вид заготовки (1)	Состояние поставки (2)	$\sigma_{в}$	$\sigma_{0,2}$	Содержание 30 вес. % бериллия δ в % (4)
		в кГ/мм² (3)		
Пруток Ø 10 мм (5) Полоса 20 × 150 мм (6) Пруток Ø 83,5 (5)	Прессованные (7)	45 40 40	30,5 23,0 24,0	20,5 17—19,0 17—20,0
Лист (8) 1,5 × 2,0 мм	Отожженный (9) Нагартованный (10)	42—47 47—55,0	33—35 40—48	8—20 5—12

Key: (1). Form of blank. (2). As-received condition. (3). in kg/mm². (4). Content of 30 weights % of beryllium δ in %. (5). Rod. (6). Band. (7). Pressed. (8). Sheet. (9). Annealed. (10). Cold-worked.

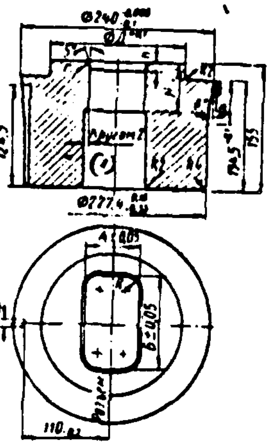

Fig. 19. Drawing/draft of matrix/die for extrusion/pressing of blanks for stamping.

Key: (1). Around.

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It is characteristic that the aluminum-beryllium alloys, not strengthened by heat treatment, in the pressed (extruded) state (after hot working) have high plasticity and in contrast to the rolled material, strongly cold-worked in the process of rolling, do not require the special heat treatment (annealing).

But technology, given in Table 8, most successfully are pressed round blanks (rods and band) of the alloys, which contain 20-30% Be with the small relationship/ratio of sides (close to 1:1) and by coefficient of deformation 2.5-5. The mechanical properties of these blanks are shown in table 10.

Forging and stamping. The thermomechanical conditions of deformation of aluminum-beryllium alloys the methods of forging and the stampings, established/installed according to the diagrams of plasticity [86], are given in table 11.

Since the aluminum-beryllium alloys in question thermally are not strengthened, but work hardening in the process of deformation contributes to an increase in strength of article, working by pressure of these alloys should be concluded on the lower limit of the temperature interval, indicated in Table 12.

Free upsetting of the casting is not of practical interest in

view of sharply limited deformation (10%). The permissible reduction with the upsetting of casting can be increased while conducting of this operation in shells of different metals (Д16, copper, brass, stainless steel). The modes/conditions of forging in the shells are represented in Table 13.

The best results are provided with the use/application of shells of steel and brass, alloy is not embrittled (cracks do not appear), which is explained by the presence of the significant magnitude of the reaction from the ring in the process of upsetting blank, which ensures deformation under the conditions of the diagram of cubic nonuniform compression.

10. Mechanical properties of semi-finished products from the aluminum-beryllium alloys.

Полуфабрикат (1)	ε в % (2)	$\sigma_в$ (3)	$\sigma_{0,2}$	δ в % (2)
		в кГ/мм²		
(4) Пруток Ø 100 мм	65,5	38,5	22	21
(5) Полоса 70 мм × × 115 мм	65	38,3	21	17—20
Пруток Ø 100 мм	75	38,9	23,8	21
Пруток Ø 85 мм	75	40,0	24,2	20,8
Полоса 20×150 мм	[illegible]7	39,9	23,2	19,7
Полоса 21×100 мм	[illegible]0	40	22,0	20,7

Key: (1). Semi-finished product. (2). in %. (3). in kg/mm². (4). Rod. (5). Band.

11. Parameters of forging and hot stamping of aluminum-beryl alloys.

Сплав (1)	(2) Температурный интервал деформации в °С	(3) ε в %
30% (вес) Be (4)	470—380	30—60
20% (вес) Be (4)	350—420	

Key: (1). Alloy. (2). Temperature interval of deformation in °C. (3). in. (4). (weight).

12. Parameters of free forging of semi-finished products from aluminum-beryllium alloys.

Вид материала (1)	Температура свободной осадки в °C (2)	ε в % (3)
Литой (4)	400	10
Предварительно-прессованный (5)	375—425	35—45

Key: (1). Form of material. (2). Temperature of free upsetting in °C. (3). in. (4). By league. (5). preliminary- pressed.

13. Modes/conditions of forging in shells of aluminum-beryllium alloys, which contain 30% (weight) of Be with 450°C.

Схема осадки (1)	Оболочка (2)	ε в % (3)
По образующей (4)	Нет оболочки (5)	10—20
»	Медь (7)	33
»	Сталь (8)	45
В торец (6)	Сталь (8)	67

Key: (1). Diagram of upsetting. (2). Shell. (3). in. (4). On generatrix. (5). Without shell. (6). In end/face. (7). Copper. (8). Steel.

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With use/application of shells of alloy D16 and copper on the lateral surface of forged blanks the cracks as a result of the low strength and the insufficient reaction from the ring are formed.

Upsetting casting in the die/stamp gives even better results. With the upsetting of casting in the die/stamp (Fig. 20) according to the diagram, shown in Table 14, on the ingots the highest reduction are provided.

Blanks after the first upsetting in the die/stamp can to be deformed satisfactorily by free upsetting on the platens, the permissible degree of deformation in this case composes 40-45%. The ingots with a diameter of 130 mm can be upset on the press 5000 m consecutively/serially in three dies/stamps according to the diagram, shown in Fig. 21 to the flat blanks with a thickness of 20-30 mm for three transitions. The mode/conditions of upsetting is given in Table 15.

Fig. 22 shows dies/stamps for obtaining the blanks of the ingots of alloys, which contain 20-30% of beryllium. Material of die/stamp steel of brand 5XHB. Temperature of heating dies/stamps of 330-380°C.

Satisfactory results on forging of cast aluminum-beryllium alloy under conditions indicated above are provided only during the use/application of dies/stamps, which have the small clearances (10 mm) in the impression of the die, when deformation leads to the insignificant free broadening of ingot; with the work with the ingots, which have the ample clearances on the lateral surface of the

stamped/die-forged blanks and on the ends/faces can appear the cracks, caused by secondary with the stresses of elongation, which appear in these zones as a result of the free broadening of alloy.

Is completely satisfactory, as it was shown, free upsetting under the press of the preliminarily pressed by extrusion blanks can be carried out.

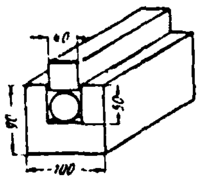

Fig. 20. Die/stamp for obtaining the blank of the ingot. Length of the dies/stamps: 1st 500; 2nd 600; 3rd 1000 mm.

14. Parameters of forging casting of aluminum-beryllium alloys, which contain 30% (weight) of Be.

Толщина заготовки по переходам в мм (1)	(2) Температура (в °C) и время (в мин) нагрева	ε в % (3)	$\sigma_в$ в кГ/мм² (4)
40		—	—
22	420—30	45	30—33
7—10		55—65	30—42

Key: (1). Thickness of blank on the transitions in mm. (2). Temperature (in °C) and time (in min) of heating. (3). in. (4). in kg/mm².

15. Modes/conditions of upsetting ingots from aluminum-beryllium alloys, which contain 30% (weight) of Be.

Толщина заготовки по переходам в мм (1)	ε в % (2)	(3) Температура нагрева в °C	(4) Время выдержки в печи
121	—		3 ч
85	30	420—450	1 ч
55	35		30 мин
2[illegible]	40	—	— (5)

Key: (1). The thickness of blank on we convert/transfer in mm. (2). in. (3). Temperature of heating in °C. (4). Holding time in furnace. (5). h min.

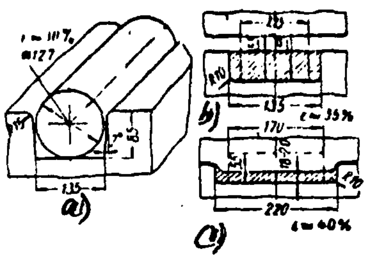

Fig. 21. Diagram of consecutive upsetting of ingot of aluminum-beryllium alloys in dies/stamps: a) as a whole; b) the secondly; c) in the third.

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The diagrams of the free upsetting (forging) of the bands pressed by extrusion and rods of the series/row of sizes/dimensions are shown in Fig. 23. Upsetting is conducted on the platens, heated to 200-300°C, according to the diagrams indicated from the preliminarily pressed blanks; are obtained slabs by the section/cut 22x250 of mm with length to 100 mm.

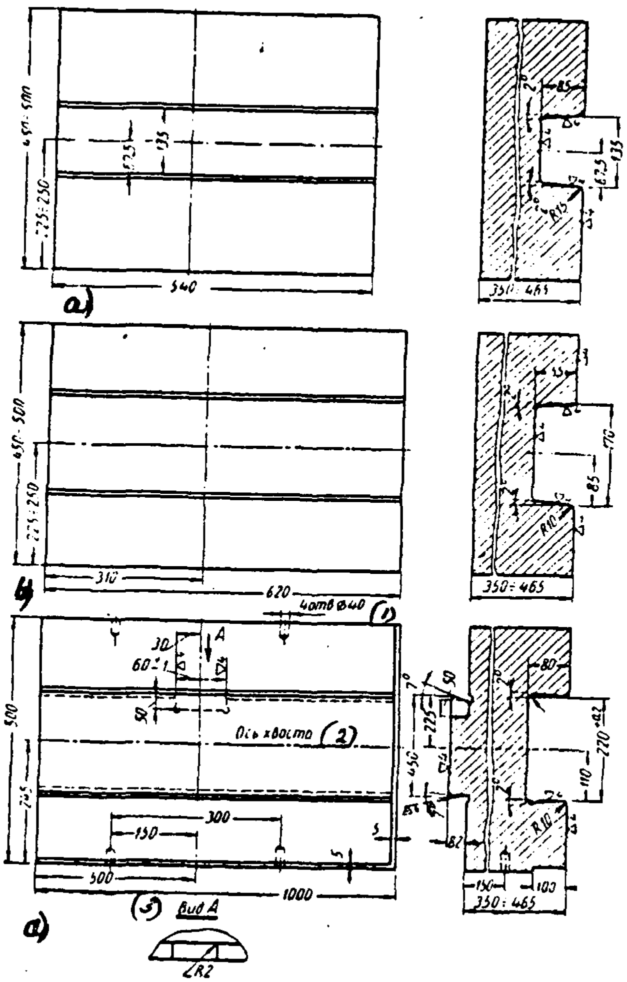

Fig. 22. Drawings/drafts of dies/stamps for the consecutive forging of the ingots: a) for the first upsetting; b) for the second upsetting; c) for the third upsetting.

Key: (1). from. (2). Axis/axle of tail. (3). Form.

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The possibility of obtaining the completely satisfactory results of forging (free upsetting) the blanks (bands and rods) pressed by extrusion on the platens is caused by a considerable increase in the technological plasticity of alloys in the state pressed by extrusion, in comparison with the cast. Fig. 24 shows the microstructure of forged material.

The machining of stampings from the aluminum-beryllium alloys. During the blanks and the stampings especially complicated on the form of the beryllium-aluminum alloys can appear separate surface cracks, which must be removed by machining. Sometimes machining is performed for the purpose of the finishing of stampings to the final dimensions. The machining of aluminum-beryllium alloys is performed in the specially equipped taking into account requirements of safety engineering locations. During turning work the cutters, equipped with plates from the hard alloys of brands BK8, BK3M, BK6M. The rate of cutting 50-100 m/min, supply 0.2-0.4 mm/rev, are applied. Possibly to rubber with the large depths.

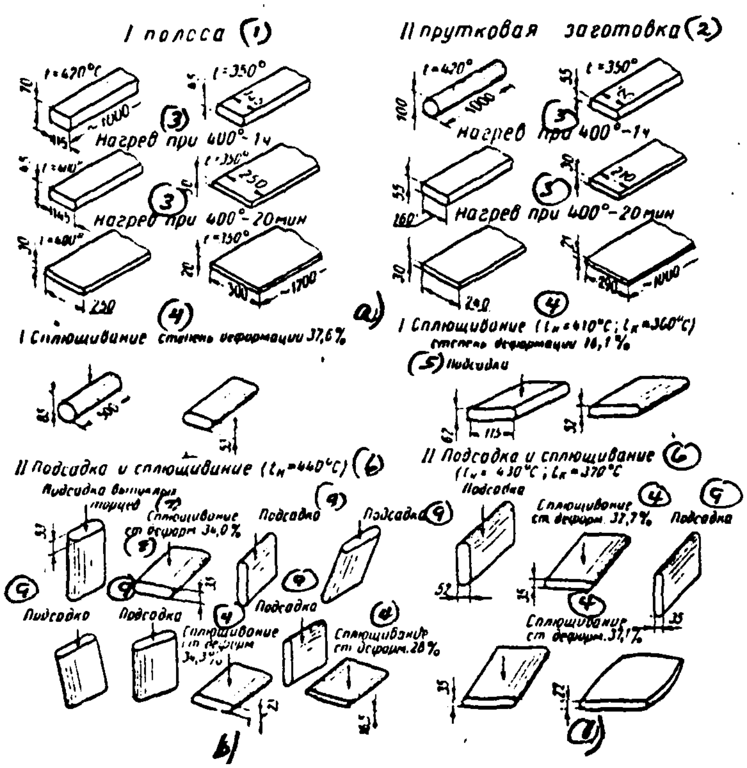

Fig. 23. The diagrams of the free upsetting (forging) of the pressed bands and rods on the press 5000 T: a) upsetting of bands and bar blanks; b) forging rod about 85 mm (temperature it began $t_{н}$ - 390°C and the end of forging $t_{к}$ - 350°C); c) forging the band with the sizes/dimensions 62x115 of mm.

Key: (1). band. (2). bar blank. (3). heating at h. (4). Flattening degree of deformation. (5). Insertion. (6). Insertion and flattening. (7). Insertion of convex ends. (8). flattening st. of de-forms. (9).

Insertion.

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In such a case, when shaving does not proceed with treatment/processing, the use/application of the lubricating and cooling liquid is possible. Milling alloys is recommended to produce with the milling cutters, equipped with the hard alloys of brands BK8, BK6M and BK3M. The modes/conditions of cutting during the milling are given in Table 16.

Drilling is recommended to also produce with the instrument, equipped with plates from the hard alloys. Grinding should be produced with the cooling. The polishing of parts is accomplished/realized by the method of the chemical effect of the aqueous solution/opening, which contains 5% H_2SO_4, 75% H_3PO_4 and 7% CrO_3 on the surface of part. As a result of chemical polishing the surface of part is covered/coated with the semipassive film of oxides. Other forms of machining are produced just as for the standard aluminum alloys under the condition of observing requirements of safety engineering.

Toxicity of beryllium and alloys, requirement of medical hygiene.

Beryllium. Working beryllium must be performed in accordance with the requirements of sanitary regulations. The following is most substantial in this case.

Beryllium in the form of blanks and finished stampings (compact material) no toxic properties possesses and it can be turned as with any common material.

Harmfulness present only those processes of working beryllium, during which occurs the isolation/liberation of vapors, finely dispersed dust and aerosols of beryllium. Therefore most adverse from a hygienic point of view are the processes of melting, welding, obtaining the cermet blanks of the powders and the machining cutting, that are accompanied by the intense isolation/liberation of vapors and dust of beryllium. During the heat working of beryllium in air, the hot die forging and the extrusion/pressing without the shells the isolation/liberation of vapors and aerosols of beryllium and oxide of beryllium also occurs, since at a temperature of more than 600-700°C on the surface of articles flying time of oxide of beryllium is formed.

Heat treatment, extrusion/pressing, forging and stamping beryllium in the hermetically sealed welded shells of harmfulness do not represent and these operations it is possible to make in the shopwide locations as working by pressure of steel or aluminum alloys.

Fig. 24. Microstructure of forged blank.

16. Modes/conditions of cutting of aluminum-beryllium alloys.

Режимы (1)	(2) Черновое фрезерование	(3) Чистовое фрезерование
Скорость в м/мин (4)	18—30	30—45
Подача в мм/мин (5)	76,2—152,4	76,2—152,4

Key: (1). Modes/conditions. (2). Roughing milling. (3). Finish milling. (4). Rate in m/min. (5). Supply in mm/min.

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The works, connected with the isolation/liberation of vapors and dust of beryllium, must be made in the specially equipped isolated/insulated locations, equipped with general exchange/total

exchange suction and exhaust ventilation so that the quantity of removed air to 15-20% would exceed air input.

All the equipment, work on which is accompanied by the isolation/liberation of vapors and finely dispersed dust of beryllium, must have local shelters or mechanical ventilation of the type of suctions. The rate of air circulation in the air scoops must be not less than 15 m/s. The rate of air circulation in the charging doors of shelters of the type of the exhaust hoods must comprise not less than 1.5 m/s.

Entire air, removed by exhaust ventilation from the specially equipped locations, before the ejection in the atmosphere must undergo two-stage cleaning/purification. As the I step/stage of cleaning/purification are utilized the filters, filled with marble grit, rubber grit, glass wool, and also bag-type filters. As the II step/stage of cleaning/purification is applied analytical fabric ФПП-15 filters of the I step/stage they undergo cleaning/purification (washing by warm soda solution/opening, by acid solutions/openings, etc.) in the special shelter. The effluents, which are formed with the washing of filters, can be thrown off in the channelization flow/discharge without the preliminary purification. Filters of the II step/stage of regeneration do not undergo.

Maximum permissible concentration of beryllium in air of production locations - 0.001 mg/m^3.

Aluminum-beryllium alloys. Working aluminum-beryllium alloys must be carried out in accordance with the requirements of sanitary regulations and instructions on hygiene of labor/work. However, these general rules and instructions do not consider entire diversity of the technological processes, which are applied at present and in essence questions of the hygiene of labor/work during working of pure beryllium are provided for. Many processes of working aluminum-beryllium alloys require conducting somewhat different, in a number of cases of less rigid preventive measures [59]. Furthermo , should be considered the physicochemical essence of each process individually. Most dangerous, from a hygienic point of view, are the processes of machining, melting and weldings of aluminum-beryllium alloys and obtaining of cermet blanks of the powder, which lead to the pollution/contamination of the air medium of production locations dust and the products of sublimation of alloy, in composition of which can occur the oxide compounds of beryllium. The systematic presence in air of aerosols and dust of beryllium can present specific danger from the point of view of the possibility of the emergence of occupational diseases among the workers and ITR.

The processes of the deformation of the aluminum-beryllium

alloys, which contain 20-50% (weight) of Be, it is permitted to produce in the shopwide locations without the conclusion of blanks into the shells, since these processes do not present on the toxicity of this danger as melting or machining, since they are conducted at a temperature less than 500°C. In this case only possible mechanical shearing of separate ones relative to the large/coarse fractions/particles of metal, which do not present practical danger in toxic sense. In this respect the processes of stamping, upsetting, extrusion/pressing and rolling essentially are similar between themselves. However, experiment shows that dust with the value of the particles of less than 5-10 μ possesses the greatest toxicity, vapors and the aerosols of alloys. In view of this the casting processes, melting, welding, machining as the most adverse from the hygienic point views and preparation of blanks of the powders of aluminum-beryllium alloys, just as beryllium, must be carried out in the special isolated/insulated locations, which strictly satisfy the requirements of sanitary regulations and instructions on safety engineering.

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Chapter 7.

Forging and stamping refractory metals and alloys.

The high melting points and recrystallization of refractory metals (Table 1) caused their use/application in the constructions/designs, which work at temperatures higher than 1000°C.

Forgings and stampings manufacture predominantly from the alloys of molybdenum and niobium by hot and warm deformation.

By the special feature/peculiarity of hot working the pressure of refractory metals and alloys is the high temperature of treatment (2400-1400°C). At mean temperature of the beginning of the hot working of structural steel and high-temperature (strength) alloys of 1200°C temperature of heating high-melting alloys is higher by 1200-200°C.

Only after the preliminary strain of ingots and conducting of vacuum recrystallization annealing, as a result of which the plasticity of refractory metals and alloys sharply grows/rises, the temperature of the beginning of working by pressure can be lowered/reduced to 1400-250°C depending on the brand/mark of alloy and thickness of the section/cut of stamping. Therefore forging and stampings must be manufactured after the preliminary strain of ingots and recrystallization annealing of blanks. It is most expedient to perform the first strain of ingots by the method of extrusion/pressing.

By the second special feature/peculiarity of working by pressure of refractory metals and alloys is the need for their protection from oxidation in the process of heating, treatment pressure and cooling, since the high rate of oxidation and the high solubility of gases during the heating, which begins with 300-500°C, lead to oxidation and embrittlement of the surface layers of the blanks being deformed. This causes a decrease in the plasticity of metals during the working by their pressure and considerable lowering of the yield of suitable.

Conducting of the heating, strain and cooling in the vacuum or the neutral medium is the best protection from oxidation.

In the case of the absence of such conditions it is necessary to produce heating and cooling in the neutral or reducing media, and strain in air.

Coating the surface of blanks or ingots with enamel in combination with the heating in the neutral medium also provides partial protection from oxidation[1].

FOOTNOTE [1]. Technology of working by pressure of refractory metals and alloys, including questions of heating, protection from oxidation, obtaining of optimum structure, high mechanical properties, manufacture of different semi-finished products by the method of extrusion/pressing, forging, stamping, rolling, drawing and other special questions are widely presented in work [89-90]. ENDFOOTNOTE.

MOLYBDENUM AND ALLOYS.

Properties and the field of application. The basic properties (Table 2-4) of the molybdenum alloys, which give advantages during their use for the articles in machine building, are: the high values of heat resistance, modulus of elasticity and the ratio of strength

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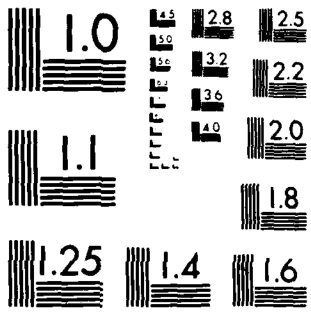

MICROCOPY RESOLUTION TEST CHART
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to the specific weight/gravity and a good thermal conductivity. Furthermore, has high value high melting point, high resisting of erosion and insensitivity to the thermal shocks.

These properties provide the reliable work of parts in the constructions/designs and the possibility to retain aerodynamic characteristics with the high temperatures and at the high velocities.

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1. Physical properties of refractory metals.

(1) Свойства	(2) Вольфрам	(3) Рений	(4) Тантал	(5) Молибден	(6) Ниобий	(7) Хром	(8) Титан	(9) Цирконий	(10) Железо	(11) Кобальт	(12) Никель
(14) Температура плавления в °C	3410	3150	2996	2625	2468	1903	1725—1820	1750—1830	1536	1490	1455
(15) Плотность в Г/см³	19,3	21,0	16,6	10,2	8,57	7,2	4,5	6,5	7,8	8,9	8,9
(16) Атомный номер	74	75	73	42	41	24	22	40	26	27	28
(17) Кристаллическая структура	(18) ОЦК	(19) ГПУ	(18) ОЦК	(18) ОЦК	(18) ОЦК	(18) ОЦК	(20) ГПУ выше 1840° С ГЦК	(21) ГПУ выше 870° С ОЦК	(22) ОЦК выше 910° С ГЦК выше 1390° С ОЦК	(20) ГПУ выше 420° С ГЦК	(23) ГЦК выше
(24) Коэффициент линейного расширения α × 10⁶/° С	4,45	6,7	6,5	5,0	7,1	6,2	8,6	6,0	12	12	
(25) Теплоемкость при 20° кал/г° С	0,034	—	0,034	0,06	0,065	0,11	0,142	0,067	0,11	0,104	0,105
(26) Теплопроводность кал/сек · см° С	0,45	0,17	0,13	0,35	0,125	0,16	—	—	0,15	12,5	0,14
(27) Электросопротивление в мком · см	5,5	21,1	15,5	5,17	19,1	12,8			9,8	5,7	[illegible]
(28) Температура кипения в ° С	5900	[illegible]	5300	4690	3300	2469	3260	3580	2450	2900	[illegible]

Key: (1). Properties. (2). Tungsten. (3). Rhenium. (4). Tantalum. (5). Molybdenum. (6). Niobium. (7). Chromium. (8). Titanium. (9). Zirconium. (10). Iron. (11). Cobalt. (12). Nickel. (14). Melting point in °C. (15). Density in g/cm³. (16). Atomic number. (17). Crystal structure. (18). bcc. (19). GTPU. (20). GTPU above 1840°C

GUK. (20). GTPU above GUK. (21). GTPU above bcc. (22). bcc above SGUK above bcc. (23). GUK above. (24). Coefficient of linear expansion. (25). Heat capacity at 20° cal/g°C. (26). Thermal conductivity кал/сек·см°C. (27). Electrical resistance in $\mu\Omega\cdot$cm. (28). Boiling point in °C.

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2. Some physical and mechanical properties of molybdenum at different temperatures.

(1) Свойства	(2) Температура в °C							
	0	20	500	1000	1200	1500	1800	2000
(3) Теплопроводность в кал/сек · см° C	0.320	0.350		0,236	0,239	0,230	0,232	0,220
(4) Удельная теплоемкость в кал/г° C	0,059	0,065	—	—	0,079	0,065	0,093	0,11
(5) Удельное электросопротивление в см · мм²/м	0,0514	—		0,325	—	0,460		—
(6) Коэффициент линейного расширения в 1/° C	—	$5{,}1 \cdot 10^{-6}$	$5{,}1 \cdot 10^{-6}$	$5{,}5 \cdot 10^{-6}$		$6{,}2 \cdot 10^{-6}$	—	$7{,}2 \cdot 10^{-6}$
(7) Модуль упругости $E \cdot 10^3$ кГ/мм²	32,5	32,0	—	22,5	18,0	—		
(8) Предел прочности в кГ/мм²		68	48	30	—	10	5	—
(9) Удлинение в %	—	20	18	20		36	50	
(10) Твердость по Виккерсу в кГ/мм²		160	85	55	44	26	14	

Key: (1). Properties. (2). Temperature in °C. (3). Thermal conductivity in cal/s·cm°C. (4). Specific heat in cal/g°C. (5). Specific resistance in cm·mm²/m. (6). Coefficient of linear expansion in. (7). Modulus/module of elasticity $E \cdot 10^3$ kg/mm². (8). Ultimate strength in kg/mm². (9). Elongation in %. (10). Vickers hardness in kg/mm².

3. Mechanical properties of alloy Mo+(0.25-0.40%) Zr (rod ⌀ of 20 mm, the degree of strain 80-85%).

(1) Температура испытания в °C	(2) Кратковременные испытания				
	(3) Модуль упругости (динамический)	(4) Предел прочности	(5) Относительное удлинение	(6) Относительное сужение	(7) Удельная ударная вязкость в кГм/см²
	(8) в кГ/мм²		(9) в %		
20	33 000	70	12	15	0.2
300	—	—	—	—	12
800	29 800	70	13		
1000	26 000	52	10		—
1200	27 000	45	15	80	
1500		16	20		2
1900	—	5	—	—	—

Key: (1). Testing temperature. (2). Short-term tests. (3). Modulus/module of elasticity (dynamic). (4). Ultimate strength. (5). Elongation per unit length. (6). Relative reduction of area. (7). Impact number in kgfm/cm². (8). in kg/mm². (9). in %.

4. Mechanical properties of heterophase molybdenum alloy BM3.

(1) Состояние поставки	(2) Температура в °C	(3) $\sigma_в$ в кГ/мм²	δ	ψ
			(4) в %	
(5) Пруток прессованный	20	80—86	—	
	1150	60—68	6—12	20
	1300	50—57		30
(6) Пруток прессованный рекристаллизованный	20	43—60	2—8	—
	1400	30—33	15—33	50
	1600	26—29	30—40	
	1800	12—13.5	48—50	—

Key: (1). As-received condition. (2). Temperature. (3). in kg/mm². (4). in %. (5). Rod, pressed. (6). Rod pressed recrystallized.

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Molybdenum relates to a number of metals with moderate transverse neutron capture and can be used in the thermal-neutron reactors.

Melting molybdenum and alloys on its basis is produced predominantly in the electric-arc vacuum furnaces. The electron-beam melting of molybdenum in essence is applied with the melting of electrodes with the subsequent remelting in the electric-arc furnaces for the purpose of grinding.

The widest application find alloys on the basis of molybdenum, since the temperature of the recrystallization of pure molybdenum is approximately 1100°C, and alloys of 1300-1600°C.

The high melting point and recrystallization makes it possible to apply molybdenum and alloys on its basis for the work at high temperatures both in that cold-worked and in that recrystallized states.

Only the complex-alloyed molybdenum alloys undergo heat treatment. Therefore the heat resistance of molybdenum and dilute alloys is determined not only by alloying, but also by strain.

Metallic molybdenum is stable in air to 500°C. At a higher temperature it noticeably is oxidized with the formation of volatile oxides. In this case occurs the diffusion of oxygen, also, into the depth of metal. Therefore heating molybdenum before the strain must be produced in reducing atmosphere or protective media.

In the constructions/designs of part from the molybdenum and the alloys on its basis they can work with shielding coatings. Without the protective coatings they can be used in the apparatuses for

single action and the settings with the neutral or protective medium.

The plasticity of molybdenum is determined by the purity of initial metal, by alloying, method of melting, by strain, heat treatment and structure. A special effect on the plasticity have interstitial impurity. The molybdenum, when the impurity content in it does not exceed solubility limit in the solid state, possesses satisfactory plasticity. A decrease in the plasticity as a result of the increased impurity content, apparently, is explained by their accumulation on the grain boundaries. Great effect on the redistribution of admixtures/impurities and, therefore, an increase in the plasticity exerts heat treatment.

The ingots, melted in the electric-arc furnaces, have the rough dendritic structure, which impedes conducting the process of plastic deformation. Dendrites are furnished almost in entire section/cut of ingot and are directed virtually in parallel to its principal axis/axle. In this case the dendrites greatest in the value will lie in the center section of the ingot. This form of the dendritic structure of the ingots of the molybdenum alloys, smelted in the arc vacuum furnaces, differs them from the usually observed structures of the ingots of other metals and alloys, melted in open furnaces. The special macrostructure of the ingots of molybdenum alloys considerably depresses the plasticity of cast metal and is caused the

need of applying the extrusion/pressing for the primary deformation of ingots.

The oxygen content in the metal of more than 0.0025% considerably decreases plasticity. In the metal are formed oxides, which predominantly are furnished along the grain boundaries. This arrangement of oxides considerably decreases intercrystalline connections/communications, plasticity during the hot working by pressure and mechanical properties of the deformed metal.

Reduction in the process of melting and modification contribute to the decrease of oxygen content along the grain boundaries and they partially raise the plasticity of metal.

An increase in the content of the alloying elements also depresses the plasticity of molybdenum.

The basic alloys of molybdenum are divided into two groups: the thermally unhardened alloys BM1 and BM2 and heterophase heat-treatable BM3П and BM4.

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The temperature effect of extrusion/pressing on the specific

pressures is shown in Fig. 1, from which it is evident that the alloys BM1 and BM4 can be subjected to extrusion/pressing with 1600-1400°C with relatively low specific pressure on the order of 80-100 kg/mm². Specific pressure for the alloy BM3П somewhat above - 110-135 kg/mm².

The highest plasticity and minimum resisting to deformation develop the alloys of molybdenum in cast state in the case of deformation after vacuum annealing. For example, the ingots of alloy BM4 after vacuum annealing with 1600°C it is possible to subject to deformation by extrusion/pressing at 1400-1300°C with the degree of deformation of 80-85%. In this case the specific pressure is 70-85 kg/mm².

After the preliminary deformation of ingots the plasticity of alloys on the basis of molybdenum sharply grows/rises. This law relates both to that thermally not hardened (BM1 and BM2) and to the heterophase (BM4 and BM3П) alloys. Fig. 3 shows the diagram of the plasticity of the alloy of molybdenum BM4, from which it is evident that after preliminary deformation and vacuum annealing the permissible deformation of ingot by upsetting at a room temperature composes 40%, which indicates the very high plasticity of alloy BM4 after the preliminary deformation of annealing. Alloy BM1 possesses also high plasticity under the analogous conditions.

The preliminary vacuum annealing of the ingots of alloy BM1 makes it possible to lower the temperature of the extrusion/pressing cast metal to 1400-1250°C.

High-strength alloys on the basis of molybdenum of the type BM3П without the annealing of the ingots virtually of deformation do not undergo.

The use/application of vacuum annealing of ingots with 1800-2000°C makes it possible to successfully carry out their deformation by extrusion/pressing with 1600°C and degree of deformation 75-85%.

The alloys on the basis of molybdenum, melted by electric arc or cathode-ray/electron-beam methods, are very sensitive to an increase in the degree of deformation. As can be seen from Fig. 2, with an increase in the degree of deformation, especially higher than 80% the specific pressure sharply grows/rises, which is obviously explained by the presence of the large dendritic structure of ingots.

The repeated deformation of alloy BM4 should be produced with extrusion/pressing with 1400-1000°C or with ductile at 1400-800°C.

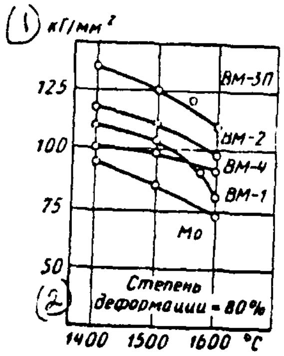

Fig. 1.

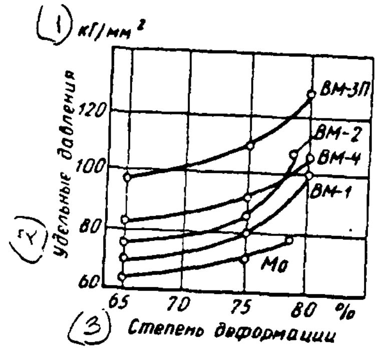

Fig. 2.

Fig. 1. Temperature effect of extrusion/pressing alloys BM1, BM2, BM3П and BM4 on specific pressure.

Key: (1). kg/mm². (2). Degree of deformation.

Fig. 2. Effect of degree of deformation of alloys BM1, BM2, BM3П and BM4 during extrusion/pressing on specific pressure $T_{прессов.} = 1600°$ C

Key: (1). kg/mm². (2). specific pressure. (3). Degree of deformation.

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It is evident from the diagram of the plasticity of high-strength alloy BM3П (Fig. 4) that after preliminary

extrusion/pressing and annealing the alloy allows/assumes upsetting to 40% at 1300°C. Therefore repeated deformation with its extrusion/pressing one should produce at 1600-1500°C, and forging and stamping with 1400-1200°C.

Forging and stamping. The presence in ingots of large dendritic structure depresses the plasticity of cast metal, the formation of liquid oxides on the surface of metal in the process of heating and forging causes the large slip of metal on the faces. The oxidation of metal at temperatures of higher than 1000°C creates the cloud of a yellow-whitish color, which impedes working conditions. Therefore forging molybdenum and its alloys, and in particular ingots, has limited application.

Forging ingots is applied if necessary of obtaining large-size forge pieces, which cannot be obtained by the volume of metal from the preliminarily pressed rod.

Forging and stamping semi-finished products from the molybdenum and the alloys on its basis are produced on the forging of steam-air, pneumatic and also hydraulic presses, primarily from the preliminarily deformed material, which has (as shown above) the plasticity considerably higher than cast, and the deformations of preliminarily deformed metal is accomplished/realized at lower

temperatures.

High-strength and heat-resistant tool steel of brands 3X2B8 and ЭИ956 is applied in connection with the high temperature of heating as the material for the dies/stamps and the faces.

Hydrogen is the best medium for heating of molybdenum and its alloys, since it is the medium of reducing. In addition to this, hydrogen during the opening of furnace provides the combustion of oxygen, which enters the furnace and the oxidizability of blank and heaters protects by this very. Argon or helium is allowed/assumed also as the medium for heating of molybdenum.

Heating ingots (blanks) can be produced in resistance furnaces, accepting in this case the heating time from the calculation of 1 min every 1-1.5 mm of the thickness of ingot. In the induction furnaces the heating time is 15-20 min to the ingot with a diameter of 150-250 mm.

Heating of the ingots prior to the forging and the stamping from the alloys with the content of zirconium of order to 0.4% must be produced at 1600-1800°C, and pure molybdenum with 1400°C.

Taking into account the large temperature interval of the

plasticity of molybdenum and its dilute alloys, forging and stamping can be concluded at 900-1000°C.

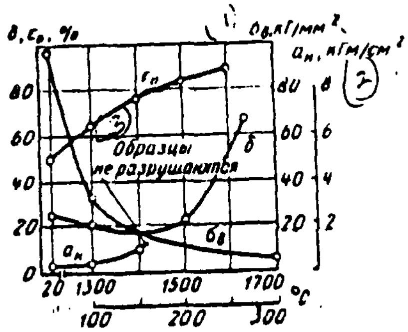

Fig. 3.

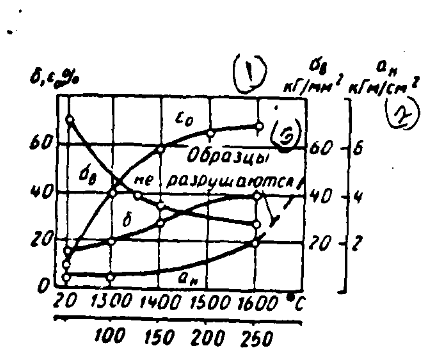

Fig. 4.

Fig. 3. Diagram of plasticity of alloy BM4.

Key: (1). kg/mm². (2). kgfm/cm². (3). Samples/specimens are not destroyed.

Fig. 4. Diagram of plasticity of alloy BM3П.

Key: (1). kg/mm². (2). kgfm/cm². (3). Samples/specimens are not destroyed.

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Forging ingots should be produced according to the diagram: upsetting in the direction of the longitudinal axis of ingot with the

degree of deformation 50-70% with the subsequent ductile to the square or rod in the perpendicular direction.

Specific pressure during forging of ingot with the content of zirconium of order to 0.4% at 1600° C and the degree of deformation 60% is approximately/exemplarily 50-60 kg/mm^2..

In connection with a considerable increase in the plasticity of molybdenum and alloys on its basis after preliminary deformation the forging and stamping the deformed blanks are accomplished/realized at lower temperatures with the preliminary vacuum annealing during 5 μ for the alloy with the content of zirconium to 0.4% with 1450°C, and with the content of zirconium to 0.2% with 1400°C.

Alloys with the content of zirconium to 0.4% are subjected to forging and stamping in the range of temperatures of 1450-1200°C. In the thin sections/cuts the forging must be concluded at 900°C. The range of forging and stamping the alloys with the content of zirconium to 0.2% composes 1350-1000°C, and in the case of thin sections/cuts forging must be concluded at 800°C.

Forging and stamping the pure preliminarily deformed molybdenum are accomplished/realized in the zone of temperatures of 1200-800°C.

Heterophase alloys are subjected to more prolonged vacuum annealing with 1600°C.

The forgings and the stampings, obtained from the preliminarily pressed rod have the best study, more uniform structure and increased mechanical properties. For stress relieving of their they subject to two-hour annealing in the vacuum 10^{-4} mm pm,cm,with 1100°C.

Before the annealing of forging and stamping mechanically they work to the complete removal/distance of oxides from the surface. Large forgings can be subjected to annealing in the neutral medium after stamping with the subsequent after annealing removal/taking the oxidized layer with thickness on the order 1.5 mm from each side.

Specific pressure with the upsetting of the preliminarily deformed nonannealed metal with the content of zirconium of order to 0.4% composes 60 kg/mm² with 1400°C and degrees of deformation 60%. After the intermediate vacuum annealing specific pressure with the temperature indicated and with the degree of deformation they depress to 50 kg/mm².

The permissible degrees of deformation depending on initial state and method of treatment are given in Table 5, from which it is evident that the greatest plasticity possesses the molybdenum,

preliminarily deformed by extrusion/pressing.

Forging the preliminarily pressed metal has an advantage over other methods of treatment in a number of cases.

They achieve by comprehensive ductile in the direction of three axes/axles the significant alignment/levelling of properties in three directions.

5. Plasticity of the dilute alloys of molybdenum depending on the initial state and method of treatment.

(1) Состояние	(2) Метод обработки			(8) Прессование в контейнере
	(3) Динамическое деформирование		(4) Статическое деформирование	
	(5) Осадка на гладких бойках	(6) Вытяжка на гладких бойках	(7) Осадка	
	(11) в %			
(9) Литое	55	20	65	85
(10) Предварительно деформированное	70	35	80	95

Key: (1). State. (2). Method of treatment. (3). Dynamic deformation. (4). Static deformation. (5). Upsetting on smooth faces. (6). Drawing on smooth faces. (7). Upsetting. (8). Extrusion/pressing in container. (9). Cast. (10). Preliminarily deformed. (11). in %.

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This forging in combination with intermediate annealing for the partial recrystallization leads to the formation of fine/small grain, and consequently to an increase in the plasticity and impact toughness. At the sufficiently refined structure of cast molybdenum impact toughness 3-5 kgfm/cm² at a room temperature is reached.

The turbine blade is one of the most widely used forms of

stamping from the molybdenum. The annular billet, close to the form of the section/cut of the blade foil, is obtained by the method of extrusion/pressing by extrusion into the die/stamp from the band for one technological junction with the large exponential deformation. Then from the preliminarily pressed annular billet in the horizontal die blade with the allowance 0.8-1.5 mm is obtained.

The extrusion/pressing blades from the alloy of molybdenum BM2 is accomplished/realized at 1400-1450°C, and stamping with 1200-1300°C.

By extrusion/pressing it is possible to manufacture the blades of large length on the equipment of low power. The considerable difference in the required powers during the extrusion/pressing and the stamping is explained by the fact that during the stamping the effort/force of press applies to the maximum area, and during the extrusion/pressing - to the section/cut of lock, which always several times of less than the length.

Stamping rotor blades from the alloys of molybdenum it is possible also successfully to accomplish on the existing technology of stamping blades from steel and high-temperature (strength) alloys on the crank presses in the dies/stamps. Initial blank - preliminarily pressed rod, is subjected to annealing in the vacuum,

heating in the medium of hydrogen or argon under conditions indicated above and to stamping for several junctions.

NIOBIUM.

The successful combination of properties (increased strength, the sufficiently high values of heat resistance, plasticity, high corrosion resistance in different media, the high melting point, average density and the low temperature interval of junction from plastic state to brittle) advances niobium into a number of the most promising refractory metals.

6. Physical properties of niobium at different temperatures.

Свойства	Показатели при температуре в °С					
	20	100	300	500	700	900
Удельная теплоемкость в кал/г · град	0,065	0,0651	0,06963	0,06875	0,07086	0,07316
Теплопроводность в кал/см · сек · град	0,125	0,13	0,140	0,151	—	—
Электросопротивление в мком · см	17,1	24,8	31,1	37,6	42,4	47,0
Коэффициент линейного расширения 10^{-6}, 1/°С	7,1	—	7,38	7,61	8,03	8,37
Модуль упругости E · 10^{3} в кГ/мм²	10,8		10,15	9,94	—	—
Свойства	Показатели при температуре в °С					
	1100	1300	1500	1600	1700	1800
Удельная теплоемкость в кал/г · град	0,07564	0,07852	0,08118	0,08267	—	0,0878
Теплопроводность в кал/см · сек · град	—	—	—	0,2	0,205	—
Электросопротивление в мком · см	50,0					
Коэффициент линейного расширения 10^{-6}, 1/°С	—	8,46	10,1	—	—	18,8
Модуль упругости E · 10^{3} в кГ/мм²		—	—			—

Key: (1). Properties. (2). Indices at temperature in °C. (3). Specific heat in cal/g·deg. (4). Thermal conductivity in cal/cm·s·deg. (5). Electrical resistance in μΩ·cm. (6). Coefficient of linear expansion 10^{-6}, 1/°C. (7). Modulus/module of elasticity E·10^{3} in kg/mm².

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By a shortcoming in the niobium is the low oxidation resistance at temperaturess higher than 250°C, interaction with nitrogen with 600-800°C and with hydrogen to 1000°C.

The physical properties of niobium depending on temperature are

given in Table 6, and the mechanical properties of the alloys, used in essence for the forging and the stamping, in table 7.

The ingots of the alloys of niobium are melted by cathode-ray/electron-beam or arc methods in the vacuum. The more alloyed alloys are obtained by dual remelting. In connection with the formation of the large dendritic structure of ingots in the process of melting, their plasticity is somewhat limited. Therefore the first deformation of ingots is accomplished/realized predominantly by extrusion/pressing at high temperatures on the order of 1400-1550°C. Is allowed/assumed if necessary and forging ingots from the dilute alloys.

Ingots from the alloy BH7 it is expedient to subject to the deformation of ductile at 1000-900°C, since this alloy contains 40% Ti and is not high-temperature (strength), but high-temperature (oxidation-resistant).

After preliminary deformation the plasticity of the alloys of niobium is sharply raised, especially, after recrystallization annealing. Therefore the subsequent deformations can be accomplished/realized by all methods of working by pressure, also, at low temperatures on the order of 1000-250°C.

Heating ingots and blanks is accomplished/realized in the furnaces of electrical resistance and induction in the medium of argon. The time of heating ingots with a diameter of 80-150 mm in the resistance furnaces is 40-60 min, in the induction furnaces 20-30 min. The fiberglass fabric and glass powder in combination with graphite is applied as a lubrication.

The use/application of preliminary vacuum annealing makes it possible to lower the temperature of the first extrusion/pressing of ingots to 1200-1350°C.

The highest plasticity the alloys of niobium acquire after preliminary deformation by extrusion/pressing and recrystallization annealing in the vacuum.

7. Mechanical properties of niobium alloys (pressed rod) during the short-term tests.

(1) Температура в °C	$\sigma_в$ (2) в кГ/мм²	$\sigma_{0,2}$ (2) в кГ/мм²	δ (3) в %	ψ (3) в %	(4) $a_н$ в кГм/см²
(5) Сплав ВН2					
20	75	70	18—28	—	27
1200	18—20	—	45—55		—
1500	8—10		—		
Сплав ВН3					
20	75—80	—	10—20	40—70	30
1100	45		21—24	70—75	—
1200	25—29		26	79—83	
1500	12,5		40—43	—	
Сплав ВН4*					
20	81	73	16	33	5—7
1100	70	—	—	—	—
1200	55	45—50	15	47	
1500	17	—	24	30	

Key: (1). Temperature in °C. (2). in kg/mm². (3). in %. (4). in kgfm/cm². (5). Alloy.

FOOTNOTE [1]. Pressed annealed rod.

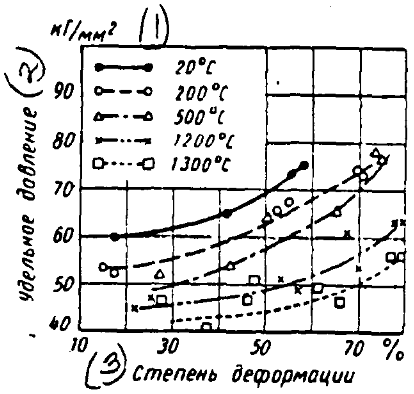

Fig. 5. Specific pressures with upsetting of preliminarily deformed and annealed alloy BH3 as a function of temperature.

Key: (1). kg/mm². (2). specific pressure. (3). Degree of deformation.

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The temperature conditions of the annealing of blanks of the alloys of niobium are the following:

alloy ... BH2 BH3.

Temperature of annealing in °C ... 1400-1350 1450-1400.

Alloy ... BH4 BH7.

Temperature of annealing in °C ... 1600-1550 1050-1000.

The high plasticity indices of the alloys of niobium after preliminary extrusion/pressing and recrystallization annealing make it possible to sharply lower the working temperature with the open methods of working by pressure, in particular with the forging and stamping.

The modes/conditions of forging and stamping the alloys of niobium after preliminary extrusion/pressing and recrystallization annealing in the large and mean sections are the following:

alloys ... BH2 BH3.

Temperature of heating in °C ... 1000-800 1200-1100.

Alloys ... BH4 BH7.

Temperature of heating in °C ... 1300-1200 1000-850.

Forging and stamping the parts of low sections/cuts from the alloys BH2 and BH3 can be accomplished/realized after annealing with

250°C, and alloy BH4 at 500°C.

Heating blanks to high and mean temperatures is accomplished/realized in the medium of argon, while heating to 250°C - in the air medium.

The lowering of the deformation temperature decreases the oxidations, considerably improves the surface and raises the yield of suitable.

Fig. 5 shows the effect of temperature and degree of deformation to the specific pressure with the upsetting of alloy BH3. As can be seen from figure, the highest specific pressure (70 kg/mm^2) is observed at 20°C, with the degree of deformation 50%. With an increase in the temperature to 200-250°C the specific pressure is depressed to 62 kg/mm^2, at 1200°C - to 48 kg/mm^2 and with 1350°C - 45 kg/mm^2.

From the diagrams of the plasticity of alloys BH2 (Fig. 6) and BH3 (Fig. 7) is evident that their permissible deformation after preliminary extrusion/pressing and recrystallization annealing composes 70%, independent of treatment temperature.

Of greatest interest for stamping the articles of low

sections/cuts made of the alloys BH2 and BH3 is working by pressure lower than temperature of the solubility of gases, i.e. at 250°C.

Forging and stamping the alloys of niobium is accomplished/realized on the equipment and the instrument, used for forging and stamping steel.

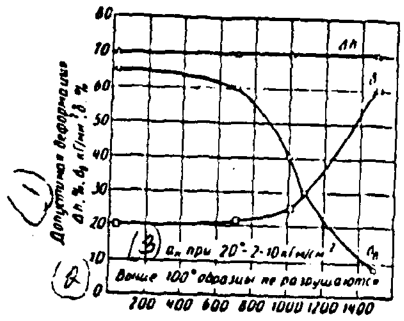

Fig. 6.

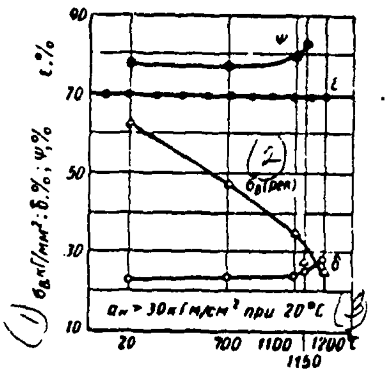

Fig. 7.

Fig. 6. Diagram of plasticity of alloy BH2.

Key: (1). Permissible deformation. (2). above samples/specimens are not destroyed. (3). with, to m/sm².

Fig. 7. Diagram of plasticity of alloy BH3.

Key: (1). kg/mm². (2). rivers. (3). kgfm/cm² with.

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